Title:	**MESH Guide: What Is Habitat Mapping?**
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Workgroup:	
MESH action:	Action 2
Version:	Version 1
Date published:	August 2007
File name:	GMHM1 What is habitat mapping.pdf
Language:	English
Number of pages:	65
Summary:	The *MESH Guide to habitat mapping* aims to provide a methodological framework for marine habitat mapping so that future mapping studies will produce high quality data and maps which are inter-compatible and their outputs can be assimilated into common, harmonised maps. It will help to make habitat maps more compatible by illustrating tried and tested standards and procedures in a step-by-step manner. This document describes the basic principles of seabed habitat mapping so that all those involved with habitat mapping can jointly make decisions about the best way to achieve the desired goals.
Reference/citation:	Foster-Smith, R., Connor, D. & Davies, J. 2007. What is habitat mapping? In: *MESH Guide to Habitat Mapping*, MESH Project, 2007, JNCC, Peterborough. Available online at: (http://www.searchmesh.net/default.aspx?page=1900)
Keywords:	
Bookmarks:	
Related information:	This document is a printable version of the MESH Guide website: http://www.searchMESH.net/default.aspx?page=1654

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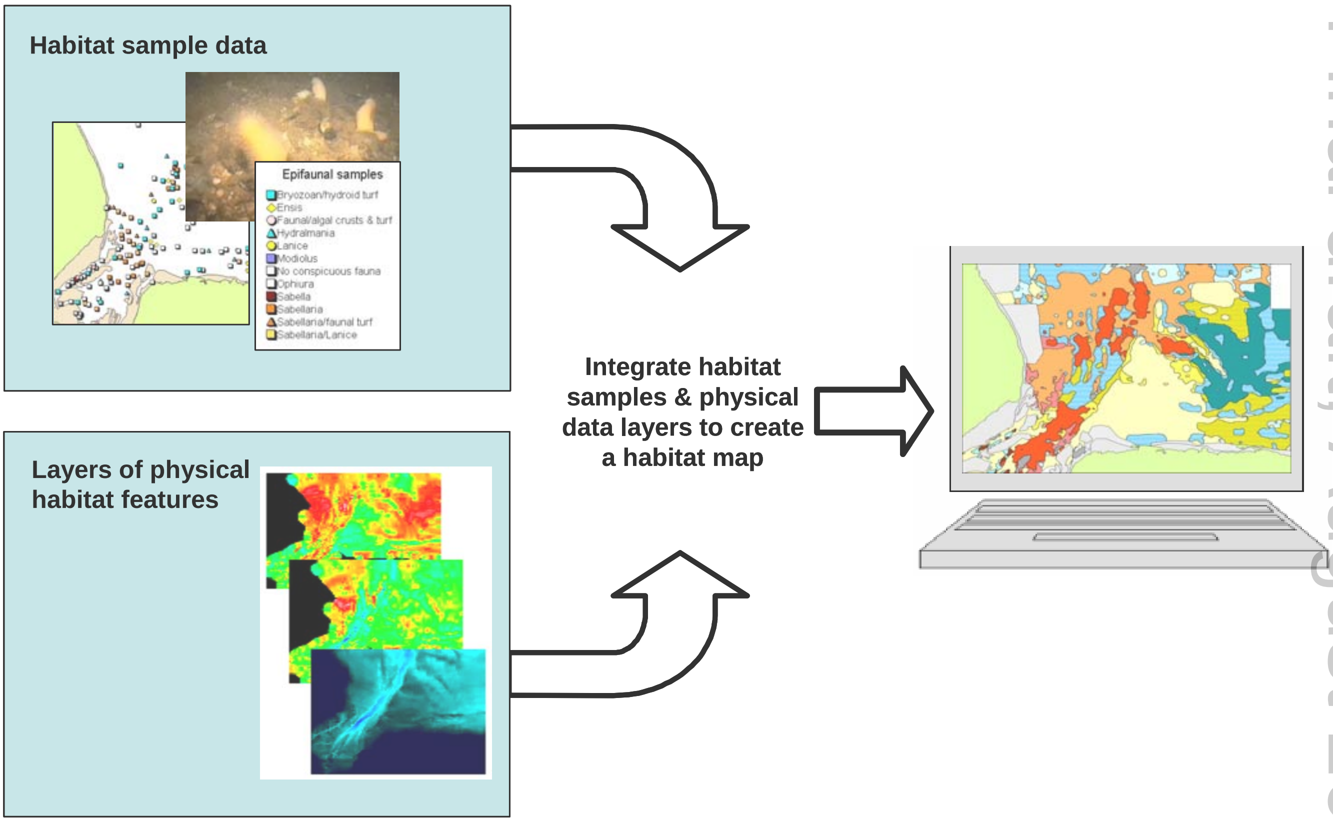
What is habitat mapping?

Bob Foster-Smith, David Connor & Jon Davies

Habitat mapping is defined by the MESH project to be:

Plotting the distribution and extent of habitats to create a complete coverage map of the seabed with distinct boundaries separating adjacent habitats.

Habitat mapping within this MESH Guide adopts a specific methodology: seabed habitat maps show the distribution of habitats by interpreting physical data layers, often derived from remote sensing, using information about seabed habitats obtained from direct sampling and observation. Only a small proportion of the seabed can be observed or sampled and the complete coverage of habitats is inferred from the association between the physical habitat data and the seabed samples so the final maps **predict** the distribution of seabed habitats. The physical habitat factors act as a **proxy** for the biological habitat data.



A summary of the habitat mapping process promoted by the MESH Project. It is important to remember that the final map is a *prediction* of the distribution of habitats.

Full coverage maps of physical habitat factors (the proxy data) are obtained either directly from some form of remote sensing (e.g. bathymetry from acoustic surveys) or derived from mathematical models of the marine environment (e.g. wave energy from weather prediction models). The inferential process to link the sample data with the physical maps is loosely termed modelling. In some cases this may be a simple process of using expert judgement whilst in other cases, the modelling might take the form of a multi-step process of transforming and combining many datasets to derive the final maps.

In summary the habitat mapping process involves surveying, collating information, analysing and modelling data to derive the habitat distribution and then designing habitat maps that are clear and fit for their intended purpose.

The present section introduces the topic of marine habitat mapping by laying the foundations needed for the user to fully understand the basic concepts, uses and limitations of marine habitat mapping and sets the scene for subsequent sections. It covers:

- **Habitat mapping in MESH** - outlines the process of mapping, including how this can be tackled over a range of scales and levels of detail. The relationship between what can be detected by survey techniques and habitat variability is discussed. The types of data needed to make maps, linking environmental variables to the physical and biological characteristics of the seabed, are outlined.
- **Why do we need habitat maps ?** - provides an overview of the main uses for habitat maps and some key policy drivers which rely on this information.
- **What are habitats?** – describes the concept of a habitat and their variability in space and scale, together with an introduction to schemes for their classification.
- **What do you want to map?** – explains some of the basic concepts of habitat mapping, concentrating on the need to clearly establish the level of habitat detail required, and the geographic area to map. It also explains why some habitats cannot be mapped, or not displayed on maps of the chosen scale.
- **How do you map habitats?** - describes some of the different approaches to habitat mapping and explains what type of data are required for different types of habitat.
- **What are the limitations of habitat mapping?** - explains what can be displayed on a map, suggests what maps can and cannot do, and explains why some habitats cannot be mapped. It also introduces the concepts of accuracy and confidence, and how maps need to change over time to reflect improved data and temporal changes in the environment.
- **Data management** - introduces the needs for sound data management, and the requirements for metadata throughout the mapping process.
- **How do you plan for habitat mapping?** **-** describes the basic considerations required to effectively plan a habitat mapping project. It sets out the main steps in the planning cycle and provides links to the relevant sections in the MESH Guide that offer further more detailed information on each topic.

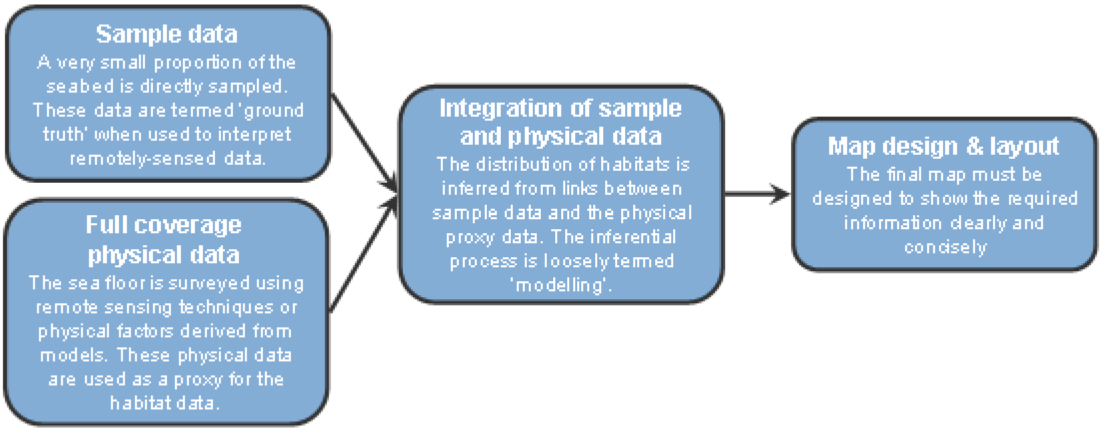
Habitat mapping in MESH

A basic knowledge of, and familiarity with all the stages of habitat mapping is required by those commissioning habitat mapping projects so that their expectations are realistic and to ensure that the work undertaken is fit for the intended purpose. From a surveyor's viewpoint, a thorough appreciation of the tasks is required so that they can be confident that they are collecting and processing data to a standard that is suitable for habitat mapping. This Introduction sets out the foundations of mapping so that all those involved with habitat mapping can jointly make decisions about the best way to achieve the desired goals.

Seabed habitat maps show the predicted geographical distribution of habitat classes. Habitat mapping, as distinct from the map itself, is the process of producing the habitat map. However, habitat mapping is really an ongoing process of developing our knowledge of the marine environment. In a sense, there is no end point to the habitat mapping process since the maps are predictive, they need testing through use and then further refinement as our knowledge improves to increase the accuracy of our predictions to boost our confidence in using maps. It is important to remember that:

A habitat map is a statement of our best estimate of habitat distribution at a point in time making best use of the knowledge we have available at that time.

In a more restricted sense, habitat mapping is the plotting of the distribution and extent of habitats as a complete coverage (sometimes termed a continuous surface) with indicative boundaries between adjacent habitats. The process involves surveying, collating information, analysing and modelling data to derive the habitat distribution and then designing habitat maps that are clear and fit for their intended purpose. The following figure summarises the habitat mapping process; this figure will appear throughout the MESH Guide although the contents of each box will reflect the particular aspect of habitat mapping being described.



A flow chart of the main stages in making a habitat map by integrating sample data and full coverage physical data.

Habitat mapping is a complex process that requires considerable expertise and resources to produce seabed habitat maps that meet the requirements of end users. Before embarking on a habitat mapping project, it is important to understand the scientific and policy drivers that establish our need for seabed habitat maps.

What are the important elements stages of in habitat mapping?

Habitat mapping combines habitat information from sample data with full coverages of physical proxy habitat factors that are known to discriminate between habitats. The latter can be obtained either directly from some form of remote sensing (e.g. bathymetry from acoustic techniques) or derived from physical models (e.g. wave energy from wave height and bathymetry). Only a small proportion of the sea floor can be directly observed or sampled and the complete coverage of habitats is inferred (predicted) from the association between the full coverage physical habitat data and samples. When properly interpreted, physical habitat factors act as a proxy for the biological habitat data. This inferential process is loosely termed 'modelling'. In some cases this may be a simple process of using expert judgement whilst in others modelling might take the form of a multi-step process of transforming and combining many data sets.

The inferential stage, combining widespread coverage of remotely-sensed information and very limited coverage ground-truth information, has profound consequences for the success of the habitat mapping process, and the quality of the final habitat map. There are sampling issues: how representative is a ground-truth sampling programme of the whole area? The remote sampling techniques will have their limitations: how successful is discrimination between habitats for different techniques and deployment strategies? Since only a small proportion of an area of the sea floor will be sampled, we can never be certain about inferred habitat distribution: how accurately does a map predict actual distribution?

Perhaps the most important consequence of the habitat mapping process is the fact that habitat maps are not purely a statement of observational data: they hypothesise about habitat distribution based on the best available information and, ideally, should be derived from well developed models linking physical factors to biological data. The maps should be further tested and their underlying models evaluated and where necessary, subsequently modified and improved over time so that we become more confident about our understanding of the actual distribution of seabed habitats. *How do I make a map?* and *How good is my map?* of the MESH Guide present more detailed information on the modelling process and how to assess map accuracy and confidence.

Bringing together remotely-sensed data and ground-truth data is fundamental to the habitat mapping process in the sense used by the MESH project. The scheme set out above will be repeated throughout the MESH Guide as the central framework for the consideration of survey design in *What do I want to map?*, making maps in *How do I make a map?* and assessing their reliability *How good is my map?*.

This framework also covers the wide range of map making activities encompassed by the MESH partnership. These range from the mapping of relatively small areas by a single survey campaign to the desk-top synthesis of many diverse available sources of data and information to derive a habitat map of a large area using desk-top modelling. These sources of data used in the desk-top modelling will be based on remote sensing but may have gone through intermediate stages of analysis and interpretation to make it suitable for analysis. So, the principles are the same in all cases although the steps involved may be more or less protracted depending on the extent of analysis and modelling involved.

Note mapping the input source data (plotting point sample data, extrapolating from point samples to create a coverage without using a remotely-sensed proxy map, plotting acoustic images on their own, creating sediment maps etc) is not habitat mapping in the sense used by MESH, although they creating such maps may be part of the habitat mapping process. Whilst this would appear a rather pedantic difference, it is vital to understanding how the habitat mapping process described by this MESH Guide is different to other methods of representing the seabed on a map.

The two ends of the range of mapping activities can be loosely termed ‘fine-scale’ and ‘broad-scale’ respectively.

Links to other sections

What do I want to map?

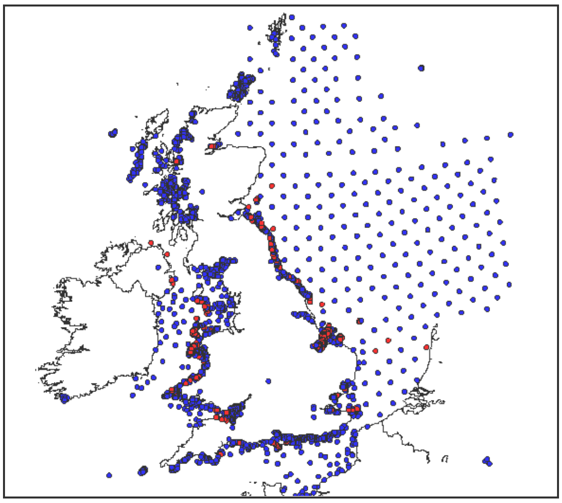
How do I make a map?

How good is my map?

Other types of habitat map

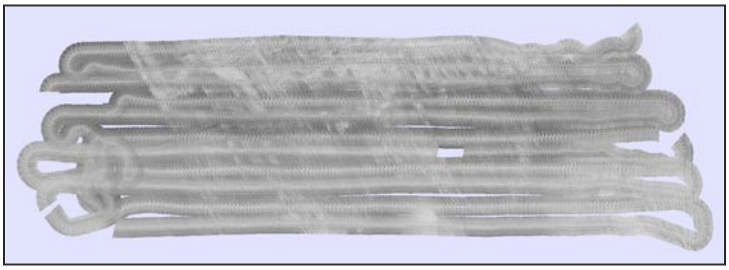
There are many other types of habitat-related geographic data that can be plotted on a map, but these are not pursued in detail in this MESH Guide.

- **Sample data** - Biological samples (e.g. from video or grabs) can be plotted on a map as point data. Once assigned to habitat types, they are integral to habitat mapping as the ground-truth data, but plot themselves can also be considered as simple habitat maps.



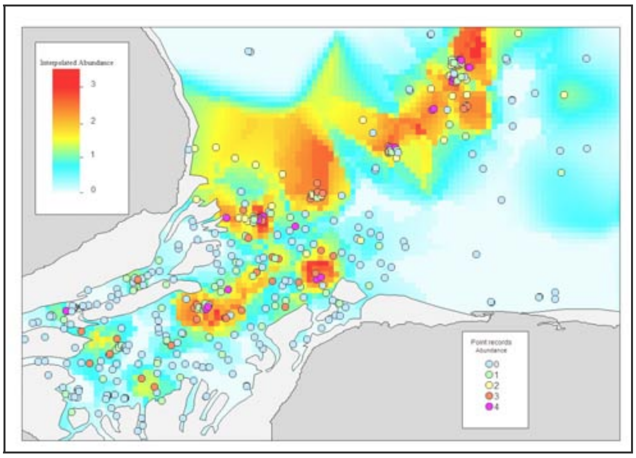
Example map of ground-truth samples

- **Acoustic data** - A plot of acoustic features (e.g. side-scan images) may be directly interpreted as habitats but need adequate ground-truthing to confirm any interpretation of habitat features.



Example of sidescan image

- **Interpolated maps** - Some point data can be interpolated to create a continuous coverage. For example, point habitat class data can be interpolated using nearest neighbour or other interpolation procedures. However, if the interpolation is not augmented by remotely-sensed data then these maps are not habitat maps in the sense used in this Guide.
- **Density plots** - Point data can be summarised in density plots or presence/absence in a predefined recording grid, such as ICES rectangles. These plots are summaries of observations where no modelling involving remotely-sensed data has been used to predict distributions.



Example of an interpolated density map

Why do we need habitat maps?

Knowledge of the spatial distribution, quality and quantity of seabed resources is fundamental to our understanding of marine ecosystems and our ability to manage human activities to deliver effective sustainable development and maintain marine ecosystem function. Maps have a wide range of applications in management, planning, policy and research and form an important and integral part of management information systems. The following are some of the areas where habitat maps are needed.

- Provide a fundamental information layer for spatial and strategic planning;
- Support sustainable use of seabed resources;
- Help implement an ecosystem-based approach to management of marine environment;
- Help protection for rare, sensitive and threatened habitats;
- Improve *State of the Environment* assessments, particularly by setting the results from monitoring stations into a wider geographic context;
- Help focus monitoring effort;
- Support the identification of marine protected areas (MPAs);
- Increase our understanding of marine ecosystem functioning – particularly its' relationship to hydrography, water column, fish communities and climate;
- Scientific research, and;
- Assess the importance, rarity and extent of habitats over local, regional, national and international scales.

In addition there is a growing demand from international policy instruments for habitat mapping information to support their aims and implementation, including:

- 1992 Habitats Directive
- 1996 North Sea Ministerial Declaration
- 2000 Water Framework Directive
- 2001 Strategic Environmental Assessment Directive
- 2003 OSPAR Biodiversity Strategy
- 2006 Maritime Green Paper
- 2007/08 Marine Strategy Directive (in draft at present)

The term 'habitat' is frequently used in these policy instruments and more widely in the scientific, policy and environmental management communities. Consequently, it has many definitions that can lead to confusion when 'habitat maps' prepared for one purpose are passed to another user from a different user group. For the purpose of clarity in this MESH Guide, our interpretation of a habitat is described in the section What are habitats?.

Links to other sections

What are habitats?

Generic needs for habitat maps

Maps have a wide range of applications in management, planning, policy and research and form an important and integral part of management information systems. The following are some of the areas where habitat maps are needed.

- Protection of the marine environment – this is generally better informed through the availability of ecological maps, allowing all users and managers to have a better understanding of the nature and distribution of seabed habitats; this is especially important because the vast areas of sea requiring management and protection are largely hidden from sight.
- Strategic planning advice to industry – the availability of habitat maps should enable advice to industry to take account of the distribution and extent of particular habitats. In particular, it should be possible to assess whether specific industries may potentially have disproportionate impacts on particular types of habitat and offer advice accordingly.
- Marine spatial planning – the emerging developments in marine spatial planning could be much better informed and follow the ecosystem-based approach to management, through the availability of the marine habitat maps. The use of broad-scale habitat maps in such planning is most appropriate at the regional level, whilst the provision of fine-scale habitat maps offers a similar benefit at a more local level.
- Marine protected areas (MPAs) – within an overall balanced approach to marine environmental management, MPAs play an important role, both in protecting specific features and in providing a refuge for biodiversity generally; as such they can provide the reference areas against which the state of the rest of the marine environment can be assessed (such as the assessment required by the Water Framework Directive). In the latter role, the identification of a suite of MPAs which representative the full range of ecological character present in a region is important. The availability of maps will facilitate the identification of such a representative suite of MPAs; this will help fulfil obligations under the OSPAR Convention which require a network of MPAs to be identified by 2010.
- Monitoring and surveillance programmes – to adequately assess the state of the marine environment, it is necessary to establish programmes which sample across the range of ecological features and have a sound geographical spread of sampling stations. The availability of national ecological maps should enable sampling stations to be distributed in a more ecologically relevant manner in national monitoring programmes.
- European Directives – implementation of the Habitats Directive, the Water Framework Directive and the proposed Marine Strategy Directive should be better informed through the availability of marine habitat maps. The latter Directive is expected to require a characterisation of the marine environment including a description of its main types of habitat and its physical and hydromorphological character.

Key policy drivers

The specific needs of key international policy drivers for habitat mapping information are outlined below:

- ***EC Habitats Directive*** - Work to identify offshore SACs is required in many European countries, requiring a number of new mapping surveys to help identify suitable sites.
- ***EC Habitats Directive –*** Member States are required to report to the EC on the status of features listed in the Directive (assess Favourable Conservation Status). For the marine habitats, the assessments need to draw upon available data on habitat distribution and extent of the marine Annex I habitats.
- ***OSPAR Convention –*** Contracting Parties are required to identify sites to contribute to OSPAR's goal of an ecologically coherent network of well-managed MPAs by 2010. This will require substantial information on the distribution of habitats to aid the identification of a representative suite of MPAs.
- ***OSPAR Convention JAMP[1] assessments*** - A set of assessments of the listed species and habitats is required by 2009 and periodically thereafter. As part of this, data are needed on the distribution and extent of each of the habitats listed.
- ***Proposed EC Marine Strategy Directive*** - This Directive is currently in final drafting stages and is expected to require an initial assessment of the state of the marine environment in about 2011. This will include the provision of information on the range of marine habitats present in each Member State, and further details and maps for habitats of conservation importance.

Further uses for habitat maps

Habitat maps are widely used beyond simply fulfilling legislative or international policy objectives. Examples of some further uses of habitat maps are outlined below.

Baseline surveys

A survey that aims to describe the range of habitats present in an area, normally with a view to establishing a standard against which future surveys may be compared, is known as a baseline survey. Such surveys can support:

- *Building an inventory and assess the proportions of different habitats*: Map-based surveys help create a balanced inventory of the major habitats (in terms of representation) in an area). Furthermore, a comparison of the geographic extent occupied by different habitats is valuable in its own right for assessing the relative importance of each habitat (in terms of its extent). Statistics on the extent of habitats can be used to quantify statements about how common or rare a habitat occurs at the regional, national and international scale.
- *Conservation measures in wider seas*: Low resolution, rapid survey permits a wide area to be covered so that areas with benthic habitats of with a high conservation status or a requirement for special management can be described and delineated. This is particularly important in the marine environment where activities in one area can have a high impact on neighbouring sites. Broad-scale information is needed to establish and justify

[1] Joint Assessment and Monitoring Programme

zones for different activities not just in sites of special conservation importance, but in the wider seas in which they lie.

- *Ecological description of areas*: Broad-scale habitat maps show the general distribution patterns of the habitats and their biological communities in an area. This is vital for building up an overview of the area that is needed to help explain the significance of unusual features, variations in specific habitat attributes (such as rare species) or the concentration of features of interest in parts of the survey area. Although maps are essentially a 'snap-shot' in time, they can lay the foundation for an understanding of dynamic processes and their spatial implications. Homogeneity, patchiness and connections between habitats are important ecological considerations that can be assessed from habitat maps.

Bringing together data as a front end for an integrated data management system

It is difficult to gain an understanding of any geographic patterns or explain any such patterns when viewing data from sample locations against a 'blank canvas'. Habitat maps offer valuable context since they integrate both physical and biological patterns into a single view. Habitat maps are often used in data management systems as:

- *Base map for showing other habitat data*: Maps can place in context available detailed habitat information, much of which are is point source data. The significance of these data can be more fully appreciated if the likely spatial extent can be estimated from the broad broad-scale habitat maps. The implications of studies of single habitat types or species can be more clearly assessed and quantified if habitat extent and distribution is known. Spatial information can be built into ecosystem models.

- *Context to consider to land and sea use patterns*: The position of habitats relative to patterns of ownership and land use will have implications for management. In this context, maps are a suitable way of summarising the interaction between different types of information.

- *Base maps for geographic query of other data*: Perhaps one of the most versatile ways to search for and use data collected by different surveys is through geographic query. If data have an associated geographic location (i.e. they are georeferenced) then they can be queried on the basis of position. Maps, especially if in a GIS (Geographic Information System) linked to electronic databases or spreadsheets, form the natural front end for geographic query and for displaying the results. This is particularly useful in the subtidal environment where different data sets may be used to help interpret an acoustic image.

Hypothesis generating and survey planning

Whilst a map is normally considered as tool to present results, it can also be used as the basis to plan further activities. Examples of such uses are:

- *Building hypothesis for scientific investigations*: Maps based on remote sensing ***predict*** the distribution of habitats or biological communities. These predictions should be based on 'rules' (or hypotheses) that can be tested and modified. Maps, used in this predictive capacity, can help to refine our knowledge of the processes that structure the composition and explain the geographic distribution of seabed habitats.

- *Planning more detailed survey*: Planning a survey based on prior knowledge of an area is a very important extension of the use of habitat maps. Broad-scale maps can be used to plan more detailed survey by ensuring an adequate and equitable coverage of the range of habitats. Similarly, basic maps showing the output of remote sensing surveys are used to plan a sampling campaign to ensure sufficient data are collected to properly ground-truth the remote data. Using maps for such planning will lead to a greater return value from detailed survey for the allocated resources.

Mapping change and monitoring management effectiveness

Habitat maps have an important role in assessing the spatial footprint of any adverse effect of human use of the marine environment, and establishing the effectiveness of any management measures that aim to control such activities. Habitat maps can make a contribution to:

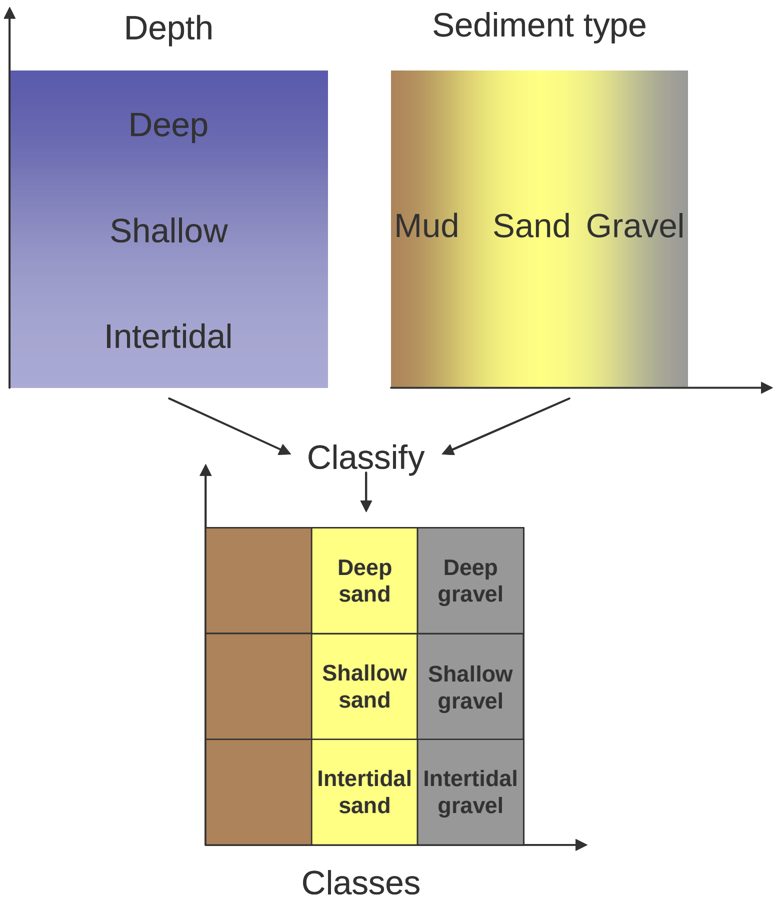
- *Establishing surveillance or monitoring programmes*: Broad-scale habitat maps are useful for developing a meaningful surveillance or monitoring programme. This may require the selection of a limited number of sites for regular detailed sampling (for example, to monitor the population of specific species of interest, general species diversity, biomass and productivity). These sites should be chosen so that the data collected are not susceptible to small fluctuations in habitat boundaries or to poor positioning. In other words, habitat maps can indicate where suitable large homogenous areas suitable for monitoring stations are located. Monitoring might also require the repeat survey of transects. Again, habitat maps can be used to select suitable locations for transects.
- *Remote survey as a surveillance or monitoring tool*: Broad-scale survey techniques might be used in conjunction with other more detailed survey techniques to indicate if any gross changes in habitat distribution take place. Awareness of such changes could trigger targeted, more detailed survey.

What are habitats?

The term **habitat** was originally defined to mean the place where an animal or plant lives (i.e. a single species). However, this can be extended to include many species together (known as a **community** or **assemblage**) instead of a single species. The use of the term 'habitat' in MESH means both the physical and environmental conditions that support a particular biological community together with the community itself. In this way a seagrass bed in shallow sand is considered to be a different habitat from rocky reefs which support kelp and other seaweeds. Similarly habitats can be further subdivided so that a rocky reef can be split into habitats that support kelp forests and habitats that support filamentous and foliose seaweeds. Examples of habitats are shown in the following figure.

Habitats are defined by the biological community and the physical structure that supports it.

In the natural world, physical, environmental and biological parameters (temperature, salinity, depth, a species' geographic distribution) change gradually from one place to the next and sharp boundaries or discontinuities are rarely encountered. It is extremely difficult to visualise and describe a habitat without introducing clear divisions of these main parameters. In very simple terms, if take an example where habitats are defined by only two physical factors where we sub-divide each factor into thirds, when we combine the two physical factors we have nine possible combinations (see following diagram). These combinations are classes. In the marine environment, there are many physical factors and many marine organisms so the process of 'classification' is more complex leading to many more habitats.



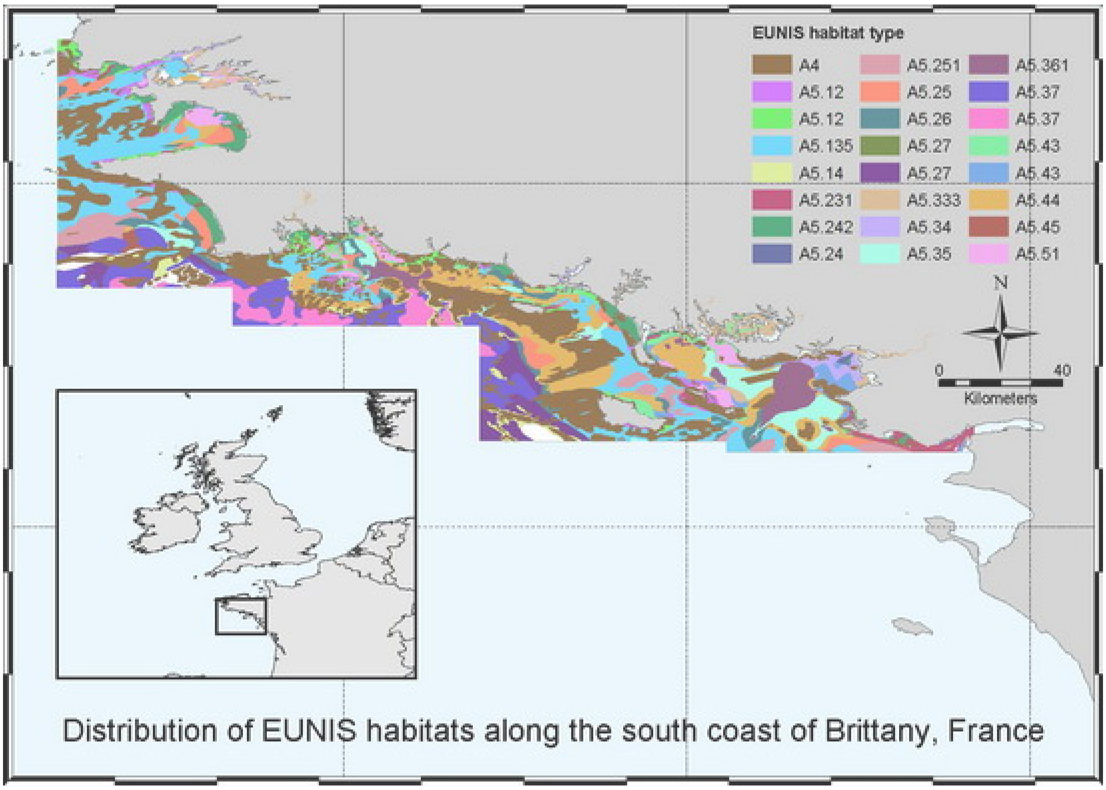
Habitat classes are defined by placing hard boundaries on continuous variables

Habitat classification schemes are devised to define habitats in a consistent way, such that similar data can be consistently assigned to particular habitat types so these data may be compared between geographic areas and/or over time. Classification schemes are designed so that habitat types can be consistently applied by different workers and across different geographical regions. Different habitat classification schemes exist because the way the environment is sub-divided is linked to the end-user's requirement. Classification schemes are often hierarchical such that broadly-defined habitats are subdivided into finer and finer units to suit end-user needs for differing levels of detail. For instance a kelp habitat can first be divided into kelp forest (plants are densely packed) and kelp park (sparsely distributed plants) and then further sub-divided based on different kinds of kelp species and their associated plants and animals (see following figure for an example).

- Marine Habitats Classification
  - Littoral rock (and other hard substrata)
  - Littoral sediment
  - Infralittoral rock (and other hard substrata)
    - High energy infralittoral rock
      - Kelp with cushion fauna and/or foliose red seaweeds
        - *Alaria esculenta* on exposed sublittoral fringe bedrock
          - *Alaria esculenta, Mytilus edulis* and coralline crusts on very exposed sublittoral fringe bedrock
          - *Alaria esculenta* and *Laminaria digitata* on exposed sublittoral fringe bedrock
        - *Alaria esculenta* forest with dense anemones and crustose sponges on extremely exposed infralittoral bedrock
        - *Laminaria hyperborea* forest with a faunal cushion (sponges and polyclinids) and foliose red seaweeds on very exposed upper infralittoral rock
        - Sparse *Laminaria hyperborea* and dense *Paracentrotus lividus* on exposed infralittoral limestone
        - *Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock
        - Foliose red seaweeds on exposed lower infralittoral rock
        - *Laminaria hyperborea* and red seaweeds on exposed vertical rock
      - Sediment-affected or disturbed kelp and seaweed communities
    - Moderate energy infralittoral rock
    - Low energy infralittoral rock
    - Features of infralittoral rock
  - Circalittoral rock (and other hard substrata)
  - Sublittoral sediment

An example of a hierarchical classification of seabed habitats, expanded to show the increasing level of detail for kelp habitats.

Habitat maps have a particular meaning within the context of the MESH project: seabed habitat maps show the predicted geographical extent and boundaries of habitat classes. Habitat maps show the sizes and shapes of the habitats and the way they relate to each other and fit together. Homogeneity, patchiness and connections between habitats are important ecological considerations that can be assessed from habitat maps. An example of a habitat map is shown in the following figure.



A habitat map (such as this one of the south Brittany coast, France) shows the distribution of habitat classes.

In the survey and mapping context of this MESH Guide, the use of the term 'habitat' refers to both the physical environment and its associated biological community, and is thus synonymous with the term '**biotope'**. As such, habitat mapping is about mapping ecologically relevant features and is more than mapping purely physical characteristics (e.g. seabed sediments), although the latter can often be used to infer much about the habitats. It is important to emphasise that:

A habitat map is a statement of our best estimate of habitat distribution at a point in time making best use of the knowledge we have available at that time.

The most important first step in the habitat mapping process is the clear definition of the type of habitats we intend to map; the next critical decisions in the mapping process are deciding what area we wish to map, and the level of detail we hope to show on the final habitat map.

Defining a habitat

Charles Darwin (1859) defined a habitat as the locality in which a plant or animal naturally lives. This classical definition still holds true today and essentially refers to the environment in which a single species lives. However for the purposes of habitat mapping it is usual to expand the concept to refer to a habitat as the place where multiple species occur together under similar environmental conditions, such that a habitat can be distinguished from surrounding habitats on the basis of both its species composition and its physical environmental characteristics (e.g. type of seabed, tidal currents, salinity etc). In this context the species are often considered to be associated together in a community and the combination of species and their environment is referred to as a biotope. On land, it is thus possible to distinguish a forest from a meadow or grassland, and to map these on the basis of their differing physical and biological characteristics. This concept is equally applicable in the marine environment, and leads to the description and mapping of habitats such as mudflats, kelp forests and seagrass beds.

It is this multi-species use of the term habitat which forms the basis of marine habitat mapping and which is the focus of this MESH Guide. Mapping of habitats for a single species (the original Darwin concept) is often more useful to consider in relation to larger more mobile species, such as fish and mammals, which can occupy a wide range of environments; this type of mapping is not considered in this Guide.

It is possible to also define habitats for the water column or pelagic environment although plotting their geographic distribution becomes more difficult because we have to include the third dimension of depth in any map. The MESH Project only considered seabed mapping and so these water column habitats are not considered further in the MESH Guide.

Unfortunately the term 'habitat' is commonly used generically in many scientific circles, as well as in management, policy and legal arenas where it often has a much broader definition. For example, the OSPAR Convention has defined a list of 'rare and threatened and/or declining habitats' (www.ospar.org/) that includes features such as 'seamounts' that are much more akin to a physical feature rather than the narrower definition used in the MESH Guide. Such uses of the term habitat are further explained in the sections Related scientific terms and Legal and policy use of the term habitat.

The MESH Project and hence this MESH Guide have adopted the more widely used term 'habitat' but we define it in its 'biotope' form to mean both the physical and biological characteristics of an area of the seabed.

Links to other sections

[Related scientific terms]

[Legal and policy use of the term habitat]

Links to websites

http://www.ospar.org/

The biotope concept – a relationship between species and their environment

The term habitat strictly then refers to the environment where the species live. In the marine realm a seabed habitat can be described in terms of its substratum (rock, sediment or biogenic reefs such as mussels), its topography and the particular conditions of wave exposure, salinity, tidal currents and other water quality characteristics (e.g. turbidity, oxygenation, nutrients) which contribute to the overall nature of a place on the shore or seabed (Connor *et al.,* 2004).

Different types of habitat support different species; whilst each species has its own particular ecological requirements or niche, it is typical to find a range of species consistently occurring together in a particular type of habitat because of their overall preference for similar environmental conditions. For instance an estuarine intertidal mudflat will typically support a range of polychaete worms and bivalve molluscs, whilst a shallow subtidal rocky habitat will support a forest of kelp and associated seaweeds and invertebrates. Such combinations of species are referred to as communities or assemblages because they recur under similar environmental conditions.

Although the character of communities (their species composition and relative densities) is influenced by biological interactions (e.g. predation, recruitment processes) and by interference from certain human activities, their overall character is very strongly determined by the nature of the surrounding abiotic conditions (i.e. their habitat). Some species will only live in mud and cannot live in sand or gravel or on rock, because of their body structure or feeding mode; others require fully saline water and cannot tolerate the salinity fluxes of estuaries, because of their physiological tolerances. This consistent relationship between the biotic and abiotic elements is encompassed in the term biotope, such that a biotope is defined as the combination of an abiotic habitat and its associated community of species (Connor *et al.,* 2004).

In the survey and mapping context of this MESH Guide, the use of the term 'habitat' refers to both the physical environment and its associated biological community, and is thus synonymous with the term biotope. As such, habitat mapping is about mapping ecologically relevant features and is more than mapping purely physical characteristics (e.g. seabed sediments), although the latter can often be used to infer much about the habitats.

Related scientific terms

The scientific community has over the years established a number of different terms, such as ecotope, physiotope, association, biocenosis and assemblage, to describe various aspects of habitat and community description. Some have specific meanings, whilst others appear to have similar meanings, having arisen in different countries. For further information on these scientific terms see Olenin & Ducrotoy (2006); see also the 2006 report of the ICES Working Group on Marine Habitat Mapping for further discussion on the definition of habitat and biotope (www.ices.dk/reports/MHC/2006/WGMHM06.pdf).

Links to websites

http://www.ices.dk/reports/MHC/2006/WGMHM06.pdf

Legal and policy use of the term habitat

Whilst the term habitat strictly speaking refers to the abiotic element of a biotope, the term is more widely used in legal and policy mechanisms to include the biological component, and thus often encompasses the biotope concept. International environmental instruments, including the EC Habitats Directive Annex I (http://ec.europa.eu/environment/nature/nature_conservation/ eu_nature_legislation/habitats_directive/index_en.htm)and the OSPAR (http://www.ospar.org/documents/dbase/decrecs/agreements/04-06E_List%20of%20threatened -declining%20species-habitats.doc) and HELCOM Conventions (http://www.helcom.fi/ environment2/biodiv/en_GB/actions/), and national mechanisms such as the UK Biodiversity Action Plan (http://www.ukbap.org.uk/), have developed lists of *habitat* types which require specific conservation and management measures. Use of the term habitat in this context typically encompasses both the communities of species and their physical environment, and therefore follows the more widely used use of the term.

Links to websites

http://ec.europa.eu/environment/nature/nature_conservation/
eu_nature_legislation/habitats_directive/index_en.htm

http://www.ospar.org/documents/dbase/decrecs/agreements/04-
06E_List%20of%20threatened-declining%20species-habitats.doc

http://www.helcom.fi/ environment2/biodiv/en_GB/actions/

http://www.ukbap.org.uk/

Why do we need to classify habitats?

There are two main reasons for using habitat classes: firstly, habitat categories are a way of reducing the complexity of the natural world to make it more understandable. Multivariate data (multiple species together with environmental variables) are synthesised into a manageable number of classes that contain biologically relevant information. A good classification helps interpret such data to produce information and add to our knowledge of the environment. Secondly, habitat classes enable the comparison of like-with-like. For example, we often ‘classify’ bottles by the colour of their glass for recycling purposes, that enables someone to compare their bottle with the ‘classes’ so they can deposit it into the correct container. In a marine habitat context, there may be little justification in comparing the species diversity of a kelp forest with a sand plain, but comparing the relative richness of an observation from a kelp forest in an area impacted by human activities with records of a kelp forest from a non-impacted area might be useful in a management context.

Typically, habitat types are arranged into a habitat classification scheme that can be defined as a structured system of habitat types (classes), often arranged in a hierarchy, where the types are clearly defined and recur in different geographical places.

Classification of samples into habitat types can be undertaken as part of the analysis of data collected within a single study and the resulting classification scheme might only be relevant to that study. Alternatively, data can be fitted to an established classification system that would then enable the local distribution of habitats to be set into a broader geographic context when compared with other maps. In practice, the two approaches are not exclusive since international or national classification systems are derived from survey data collected at local level and should be flexible enough to accommodate new data. Historically, it was the default approach to define a new locally-based classification scheme using the data from a geographically limited area of a single study. This is becoming increasingly inappropriate for a number of reasons:

- The mapped classes may not be relevant to a broader description of ecosystems;
- The resultant maps are not compatible with other studies, especially if the classes are derived in very different ways;
- The derived datasets (maps) cannot be aggregated with other datasets to make maps covering larger areas without translation of the local classification schemes to a common system;
- The derived data cannot be used to assess the relative importance of a 'local' habitat within a international, national or regional context, which reduces the value of that study to the wider scientific and management community.
- The adoption of a unified classification scheme appropriate to a broader geographical area provides a context in which to place the results of a particular study and a standard by which the data are interpreted. It ensures that similar habitats can be compared with one another across a broad geographic range. Such standardised interpretation of data is increasingly demanded by end-users, who require knowledge of the relevance of the mapped data within a local study area in a wider regional, national or international context.

Standardising existing habitat map data to a single classification scheme and preparing guidelines to promote more standardised interpretation of the new map data were two of the key aims of the MESH project.

What is a habitat classification scheme?

A habitat classification scheme can be defined as a structured system of habitat types (classes), often arranged in a hierarchy, where the types are clearly defined and recur in different geographical places. An understanding of how a classification system is structured is a pre-requisite for any attempt to use that system for mapping. Worldwide, there are many classification schemes relevant to marine habitats and whilst many have a hierarchical structure, others are not hierarchical, providing instead a structured list of habitat attributes. In a hierarchical system habitat classes are described at various levels of detail and are nested so that a numerous detailed habitats lay within a smaller number more broadly-defined habitat classes. Detailed habitats (at low levels in the hierarchy) that are grouped into the same upper-level class are more similar to each other than to those in another class.

A broad classification scheme must be well managed to ensure that the classes are relevant and to avoid unnecessary proliferation of classes. It is a guiding principle that classes should recur under similar environmental conditions in other geographical areas to justify their inclusion within a classification system.

As existing classification schemes evolve and develop, there is a tendency to periodically publish new versions, which can differ significantly to previous versions (especially during the development phase of the classification system). Consequently, analyses of samples and or maps made using different versions of the same classification system may be more or less incompatible or require special translation. There is a need for all involved in a mapping project to be aware of the developments of the scheme. Surprisingly, such oversights can be quite common, especially where multiple contractors are involved.

What classification schemes are available?

Within Europe, there is a single pan-European habitat classification scheme together with a number of 'national' and 'local' schemes which encompass marine habitats. These schemes are briefly reviewed below. Such classification schemes are intended to aid the consistent interpretation of habitat data for use in nature conservation to help prioritise conservation action and to support the management of protected areas.

The European Environment Agency (EEA) developed a classification scheme for habitats as part of its EUNIS system (**E**uropean **N**ature **I**nformation **S**ystem) for managing species, site and habitat information. The EUNIS habitat classification scheme is a pan-European classification of terrestrial, freshwater and marine habitats that was developed for the EEA by the European Topic Centre on Biological Diversity (ETC/BD). The latest version can be accessed from the EUNIS website (http://eunis.eea.europa.eu/habitats.jsp).

EUNIS is the only classification system covering all European waters and consequently was adopted by MESH as the standard scheme to which all its habitat mapping data are being presented. This ensures data arising from MESH are in a common European classification system and that EUNIS is thoroughly tested as to its suitability to marine habitat mapping. However, EUNIS is still under development (JNCC are responsible for promoting its further development for the north-east Atlantic and Baltic Sea) and its use within MESH provides an opportunity to test, and if necessary recommend modifications to, the classification to ensure it is of practical use in north-west Europe. The EUNIS habitat classification is a hierarchical scheme. There are six hierarchical levels and discrimination between marine habitats is largely based on the concepts of biological zone (littoral, infralittoral, circalittoral etc), substrate type, hydrodynamic energy (i.e. wave exposure, tidal strength), environmental variables (e.g. salinity) and characterising species. A more detailed outline of the hierarchical structure is presented in the section EUNIS marine habitat classification.

Prior to the expansion of the EUNIS habitat scheme into the marine environment, a number of countries developed their own national marine classification schemes. In the UK, the JNCC developed the *Marine Habitat Classification for Britain and Ireland* (Connor *et al.*, 2004; www.jncc.gov.uk/MarineHabitatClassification); France developed the *ZNIEFF-MER classification* (Dauvin *et al.,* 1994); in the Netherlands, Bouma *et al.,* (2004) developed the *Dutch Ecotope System for Coastal Waters* where the term 'ecotope' is analogous to the term 'habitat' as used by MESH. These schemes are described in the section National classification schemes.

Many schemes were derived from the analysis of in-situ observations or remotely collected samples (by grab, core or dredge) of the biological communities supported by data on the prevailing physical environmental conditions. Often, spatial information on these habitat-defining factors is not available, and/or these factors cannot be recorded by standard remote sensing tools (see the section What are the limitations of habitat mapping?). Consequently, other habitat classification schemes were developed that were more closely linked to habitat mapping. For example, the Life form classification was developed in UK based on the overall 'shape' of the dominant species and the nature of the seabed (Bunker & Foster-Smith 1996); further information on this life-form classification scheme is provided in the file Lifeform classification for mapping.doc. It was used for mapping intertidal habitats around Wales (Wyn *et al*., 2006), and subtidal habitats in possible Special Areas of Conservation (see UKMarine SACs Project website – http://www.ukmarinesac.org.uk – and the Marine Monitoring Handbook website – http://www.jncc.gov.uk/page-2430).

The development of the marine landscape concept (sometimes also termed seascapes) is far less advanced than habitat classification systems. A classification for UK waters is now available (Connor *et al.,* 2006; www.jncc.gov.uk/UKSeaMap), and is being further developed within other MESH countries. The marine landscape concept is equivalent to the 'habitat complex' concept in EUNIS. At present there are very few marine habitat complexes defined in EUNIS.

Links to other sections

EUNIS marine habitat classification

National classification schemes

What are the limitations of habitat mapping?

Links to resources

Lifeform classification for mapping.doc

Links to websites

http://eunis.eea.europa.eu/habitats.jsp

http://www.jncc.gov.uk/MarineHabitatClassification

http://www.ukmarinesac.org.uk

http://www.jncc.gov.uk/page-2430

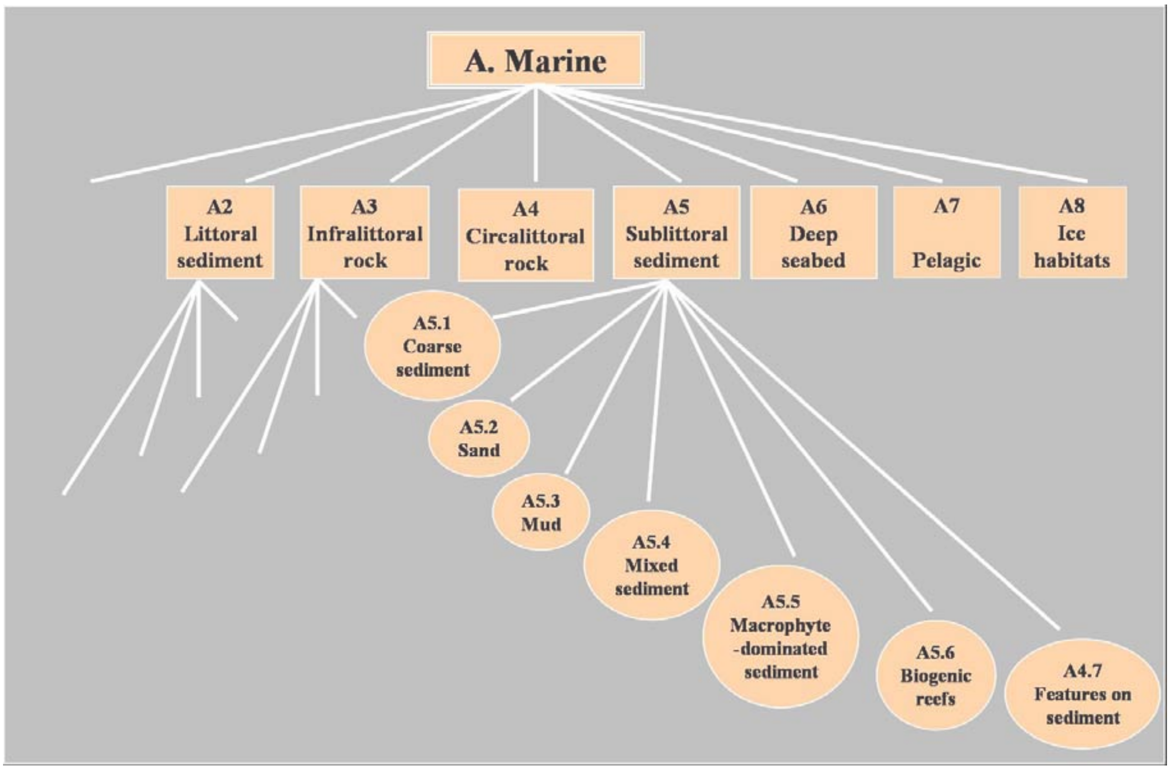
http://www.jncc.gov.uk/UKSeaMap

EUNIS marine habitat classification

The European Environment Agency (EEA) developed a classification scheme for habitats as part of its EUNIS system (**E**uropean **N**ature **I**nformation **S**ystem) for managing species, site and habitat information. The latest version can be accessed from the EUNIS website (http://eunis.eea.europa.eu/habitats.jsp). It is a pan-European classification of terrestrial, freshwater and marine habitats that was developed for the EEA by the European Topic Centre on Biological Diversity (ETC/BD).

The marine habitat section of the EUNIS classification scheme can be accessed online (http://eunis.eea.europa.eu/habitats-code-browser.jsp?habCode=A - factsheet). There are six hierarchical levels, and the example provided below is designed to help understand how the classification is constructed. Full details of the system are available from the EUNIS website. The official notes on the 2004 version to the system (including useful diagrams and glossary) are provided in the resources folder in file EUNIS_Habitat_Classification_Revised_2004.pdf.

The first level of the hierarchy splits off marine habitats (signified by code letter 'A') from coastal and terrestrial habitats. The remaining levels are illustrated below and use a numbering system for further sub-divisions.



An illustration of the hierarchical classification in EUNIS showing the use of alphanumeric codes to indicate the levels (down to level 3 only)

In general Level 2 uses the biological zone and the presence/absence of rock as classification criteria, so A1 = littoral rock and other hard substrata while A5 = Sublittoral sediment (see illustration). Level 3 introduces energy into the classification for hard substrata, and splits the softer substrata by different sediment types, so A1.1 = High-energy littoral rock while A5.4 = Sublittoral mixed sediments.

Up to this point, the classification has been based entirely on ‘physical’ characteristics and the concept of biological zones. References to specific taxa are first introduced at Level 4, where major epifaunal taxa are used to discriminate rocky habitats. However, for soft substrata, discrimination is still based on the ‘physical’ and zonal attributes, so A1.11 = *Mytilus edulis* and/or barnacle communities while A5.44 = Circalittoral mixed sediments.

At Level 5, discrimination is based on both physical and biological characteristics of the habitats. In the softer substrates, some classes are defined predominantly by infauna and others by epifauna, and these often include named species. So, A1.112 = *Chthamalus* spp. on exposed upper eulittoral rock, while A5.441 = *Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment.

Level 6, the highest discriminant level in EUNIS, frequently describes notable variations in community structure of level 5 habitats. So, A1.1121 notes the presence of *Chthamalus montagui* and *Chthamalus stellatus*, but A1.1122 notes *Chthamalus montagui* and *Lichina pygmaea*. The different characterising taxa are associated with differing environmental characteristics of the habitat.

- Habitat Classification Categories
  - A1 - Littoral rock and other hard substrata
    - A1.1 - High energy littoral rock
      - A1.11 - [Mytilus edulis] and/or barnacle communities
        - A1.111 - [Mytilus edulis] and barnacles on very exposed eulittoral rock
        - A1.112 - [Chthamalus] spp. on exposed upper eulittoral rock
          - A1.1121 - [Chthamalus montagui] and [Chthamalus stellatus] on exposed upper eulittoral rock
          - A1.1122 - [Chthamalus] spp. and [Lichina pygmaea] on steep exposed upper eulittoral rock
        - A1.113 - [Semibalanus balanoides] on exposed to moderately exposed or vertical sheltered eulittoral rock
      - A1.12 - Robust fucoid and/or red seaweed communities
      - A1.13 - Mediterranean communities of upper mediolittoral rock
      - A1.14 - Mediterranean communities of lower mediolittoral rock very exposed to wave action
      - A1.15 - Fucoids in tide-swept conditions
    - A1.2 - Moderate energy littoral rock
    - A1.3 - Low energy littoral rock
    - A1.4 - Features of littoral rock
  - A2 - Littoral sediment
  - A3 - Infralittoral rock and other hard substrata
  - A4 - Circalittoral rock and other hard substrata
  - A5 - Sublittoral sediment
    - A5.1 - Sublittoral coarse sediment
    - A5.2 - Sublittoral sand
    - A5.3 - Sublittoral mud
    - A5.4 - Sublittoral mixed sediments
      - A5.41 - Sublittoral mixed sediment in low or reduced salinity (lagoons)
      - A5.42 - Sublittoral mixed sediment in variable salinity (estuaries)
      - A5.43 - Infralittoral mixed sediments
      - A5.44 - Circalittoral mixed sediments
        - A5.441 - [Cerianthus lloydii] and other burrowing anemones in circalittoral muddy mixed sediment
          - A5.4411 - [Cerianthus lloydii] with [Nemertesia] spp. and other hydroids in circalittoral muddy mixed sediment
        - A5.442 - Sparse [Modiolus modiolus], dense [Cerianthus lloydii] and burrowing holothurians on sheltered circalittora
        - A5.443 - [Mysella bidentata] and [Thyasira] spp. in circalittoral muddy mixed sediment
        - A5.444 - [Flustra foliacea] and [Hydrallmania falcata] on tide-swept circalittoral mixed sediment
        - A5.445 - [Ophiothrix fragilis] and/or [Ophiocomina nigra] brittlestar beds on sublittoral mixed sediment
        - A5.446 - Sandy mixed sediment with [Alcyonidium diaphanum]
      - A5.45 - Deep mixed sediments
      - A5.46 - Mediterranean communities of coastal detritic bottoms
      - A5.47 - Mediterranean communities of shelf-edge detritic bottoms
    - A5.5 - Sublittoral macrophyte-dominated sediment
    - A5.6 - Sublittoral biogenic reefs
    - A5.7 - Features of sublittoral sediments
  - A6 - Deep-sea bed
  - A7 - Pelagic water column
  - A8 - Ice-associated marine habitats

Screen shot from the EUNIS websites showing an example of the EUNIS classification hierarchy for marine habitats (note, several higher classes have been expanded to illustrate the sub-units)

Each entry in the hierarchical tree is linked to a database that provides a pre-formatted fact sheet, giving a detailed description of the habitat, an annotated list of the characterising species and a table of other information relevant to characterising the habitat (e.g. the biological zone, substratum type etc). These are illustrated in the three screen shots below. The information can be downloaded as a single 'fact-file' (in .pdf format); an example is available for download from the resource folder (A1_112 Habitat Factsheet.pdf). Many of the data in these fact sheets are sources from the marine habitat classification for Britain and Ireland (Connor *et al.,* 2004).

Downloadable PDF

[Chthamalus] spp. on exposed upper eulittoral rock

General information | Species | Other info

English name **[Chthamalus] spp. on exposed upper eulittoral rock**

EUNIS habitat type code **A1.112** Level 5

Description (English)

Very exposed to moderately exposed upper and mid eulittoral bedrock and boulders characterised by a dense community of barnacles, including [Chthamalus montagui], [Chthamalus stellatus] and [Semibalanus balanoides], and the limpet [Patella vulgata]. Damp cracks and crevices in the rock provide a refuge for small individuals of the mussel [Mytilus edulis] and the winkles [Melarhaphe neritoides] and [Littorina saxatilis]. These crevices can also be occupied by encrusting coralline algae and the anemone [Actinia equina]. Black patches of the lichen [Verrucaria maura] may be found in this zone. There is much regional variation in the distribution and zonation of [Chthamalus] spp. On the west coast [Chthamalus] spp. dominate the upper eulittoral, often forming a distinct white band above a darker band of [S. balanoides] in the mid eulittoral zone. [C. montagui] is better adapted to resist desiccation and, therefore, extends further up the shore. On some shores, particularly in the south-west, [Chthamalus] spp. is the dominant barnacle throughout the eulittoral zone (Cht.Cht). On other shores, particularly in the south, [Lichina pygmaea] can form a distinct zone (Cht.Lpyg). Situation: Cht is found below the black lichen [Verrucaria maura] (Ver.B or Ver.Ver) on very exposed shores and above the mussel [Mytilus edulis] and barnacle biotope (MytB). On slightly less exposed shores the wrack [Fucus vesiculosus] is able to survive and a mixed barnacle and [F. vesiculosus] biotope may occur (Sem.FvesR) beneath Cht. On such moderately exposed shores Cht may still occur on steep and vertical faces, while fucoids dominate the flatter areas (Sem.FvesR or Fves), though these communities should not be confused with Sem.FvesR. Cht can also occur above Sem. On very sheltered sea lochs in Argyll, West Scotland [Chthamalus] spp. are unusually abundant in the upper eulittoral zone.

Source:

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B. (2004)

Relationships with other classifications

Classification	Code	Title	Relation Type
EUNIS Habitat Classification 200308	A1.112	Barnacles and [Patella] spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock	wider
EUNIS Habitat Classification 200202	A1.112	Barnacles and [Patella] spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock	same
EUNIS Habitat Classification 199910	A1.112	Barnacles and [Patella] spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock	same
CORINE Land Cover	4.2.3.	Intertidal flats	n/a
Marine Habitat Classification Britain/Ireland 0405	LR.HLR.MusB.Cht	**Chthamalus** spp. on exposed eulittoral rock	source
MNCR BioMar 97.06 (Britain & Ireland)	ELR.MB.BPat	Barnacles and [Patella] spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock	same
	A	Marine habitats	Ancestor
	A1	Littoral rock and other hard substrata	Ancestor
	A1.1	High energy littoral rock	Ancestor
	A1.11	[Mytilus edulis] and/or barnacle communities	Parent

Downloadable PDF

[Chthamalus] spp. on exposed upper eulittoral rock

General information | **Species** | Other info

Species characteristics for habitat type

Species Scientific Name	Biogeographic Region	Abundance	Frequencies	Faithfulness	Comment
Chthamalus montagui	Biogeographic region not detailed in original data set	Abundant	Occurs in 81-100% of samples		Species mentioned in habitat definition as characterising
Melarhaphe neritoides	Biogeographic region not detailed in original data set	Common	Occurs in 21-40% of samples		Species mentioned in habitat definition as characterising
Patella vulgata	Biogeographic region not detailed in original data set	Common	Occurs in 61-80% of samples		Species mentioned in habitat definition as characterising
Chthamalus stellatus	Biogeographic region not detailed in original data set	Frequent	Occurs in 61-80% of samples		Species mentioned in habitat definition as characterising
Littorina saxatilis	Biogeographic region not detailed in original data set	Frequent	Occurs in 61-80% of samples		Species mentioned in habitat definition as characterising
Semibalanus balanoides	Biogeographic region not detailed in original data set	Frequent	Occurs in 41-60% of samples		Species mentioned in habitat definition as characterising
Actinia equina	Biogeographic region not detailed in original data set	Occasional	Occurs in 41-60% of samples		Species mentioned in habitat definition as characterising
Mytilus edulis	Biogeographic region not detailed in original data set	Occasional	Occurs in 61-80% of samples		Species mentioned in habitat definition as characterising

Screenshots from the EUNIS website showing fact sheet information for the habitat A1.112: *Chthamalus* spp. on exposed upper eulittoral rock

Links to resources

EUNIS_Habitat_Classification_Revised_2004.pdf

A1_112 Habitat Factsheet.pdf

Further information and worked examples on the EUNIS habitat scheme are provided in the following files that are also available for download:

Worked example: EUNIS application v3.doc

Worked example: EUNIS marine proposal proforma v3.xls

Links to websites

http://eunis.eea.europa.eu/habitats.jsp

http://eunis.eea.europa.eu/habitats-code-browser.jsp?habCode=A – factsheet

National classification schemes

One of the most comprehensive 'national' schemes is the Marine Habitat Classification for Britain and Ireland (Connor *et al.*, 2004; www.jncc.gov.uk/MarineHabitatClassification), which has close similarities to EUNIS, using the same discriminatory criteria, but differs in its nomenclature and classification codes. The six hierarchical levels of the classification comprise:

Level 1	Environment (marine)
Level 2	Broad habitat types

Level 3	Habitat complexes
Level 4	Biotope complexes
Level 5	Biotopes
Level 6	Sub-biotopes

The classification was revised in 2004 and is based primarily on the analysis of benthic sample data from an extensive twelve-year survey programme. Detailed introductory notes to the system are included in the file MNCR_04_05_introduction.pdf . The revised system has recently been used to further populate the marine section of the EUNIS classification. A table showing correlations between this classification system and others (including EUNIS, 'Annex I' habitats from the EC Habitats Directive, OSPAR and the UK Biodiversity Action Plan) is also provided in the file EUNIS habitats correlation table.pdf . In a habitat mapping context, the classification for Britain and Ireland has been applied, for example, in many studies of Special Areas of Conservation (SACs) (see www.searchMESH.net/metadata for examples) and a major intertidal survey of the coast of Wales (Brazier *et al.,* 2006).

EUNIS level	EUNIS code	EUNIS name	Relation to JNCC 0405 type	JNCC 04.05 code	JNCC 04.05 name	JNCC 04.05 EUNIS Level
1	**A**	**Marine habitats**	=	**-**	**Marine habitats**	**1**
2	**A1**	**Littoral rock and other hard substrata**	=	**LR**	**Littoral rock (and other hard substrata)**	**2**
3	**A1.1**	**High energy littoral rock**	=	**LR.HLR**	**High energy littoral rock**	**3**
4	**A1.11**	**[Mytilus edulis] and/or barnacle communities**	S	**LR.HLR.MusB**	**Mussel and/or barnacle communities**	**4**
5	A1.111	[Mytilus edulis] and barnacles on very exposed eulittoral rock	S	LR.HLR.MusB.MytB	*Mytilus edulis* and barnacles on very exposed eulittoral rock	5
5	A1.112	[Chthamalus] spp. on exposed upper eulittoral rock	S	LR.HLR.MusB.Cht	*Chthamalus* spp. on exposed eulittoral rock	5
6	A1.1121	[Chthamalus montagui] and [Chthamalus stellatus] on exposed upper eulittoral rock	S	LR.HLR.MusB.Cht.Cht	*Chthamalus* spp. on exposed upper eulittoral rock	6
6	A1.1122	[Chthamalus] spp. and [Lichina pygmaea] on steep exposed upper eulittoral rock	S	LR.HLR.MusB.Cht.Lpyg	*Chthamalus* spp. and *Lichina pygmaea* on steep exposed upper eulittoral rock	6
5	A1.113	[Semibalanus balanoides] on exposed to moderately exposed or vertical sheltered eulittoral rock	S	LR.HLR.MusB.Sem	*Semibalanus balanoides* on exposed to moderately exposed or vertical sheltered eulittoral rock	5
6	A1.1131	[Semibalanus balanoides], [Patella vulgata] and [Littorina] spp. on exposed to moderately exposed or vertical sheltered eulittoral rock	S	LR.HLR.MusB.Sem.Sem	*Semibalanus balanoides, Patella vulgata* and *Littorina* spp.on exposed to moderately exposed or vertical sheltered eulittoral rock	6
6	A1.1132	[Semibalanus balanoides], [Fucus vesiculosus] and red seaweeds on exposed to moderately exposed eulittoral rock	S	LR.HLR.MusB.Sem.FvesR	*Semibalanus balanoides, Fucus vesiculosus* and red seaweeds on exposed to moderately exposed eulittoral rock	6
6	A1.1133	[Semibalanus balanoides] and [Littorina] spp. on exposed to moderately exposed eulittoral boulders and cobbles	S	LR.HLR.MusB.Sem.LitX	*Semibalanus balanoides* and *Littorina* spp. on exposed to moderately exposed eulittoral boulders and cobbles	6

An extract from the habitat correlation table, comparing the EUNIS scheme with that for Britain and Ireland (denoted as JNCC 04.05). In the central column, '=' shows an exact match exists between the different classification systems and 'S' indicates the EUNIS habitat was sourced from the classification for Britain and Ireland

In the Netherlands, Bouma *et al.,* (2004) have developed the **Dutch Ecotope System for Coastal Waters**. The term 'ecotope' is analogous to the term 'habitat' as used by MESH. The authors describe the system as:

> "a tool enabling the potential occurrence of habitats on the bed of brackish and saline national waters to be mapped, to be predicted and to be compared with a previous situation. Physical environmental factors mainly determine via several processes the occurrence of habitats and with it ecological communities. Based on the main physical environmental factors and processes, we selected a number

> of abiotic classification characteristics and accompanying variables that may represent these environmental characteristics in a map. Based on the variables and class boundaries we describe the ecotopes and set them up in a hierarchically arranged ecotope system."

The system can be regarded as an example of a 'local' classification scheme, as it focuses on coastal shallow water systems. It uses similar discriminatory criteria to those in EUNIS, but there are some differences in emphasis that reflect the prominence and importance of factors such as salinity and depth in differentiating habitats in the extensive shallow water system (<20 metres) that is prevalent in The Netherlands. The system is explained fully in the paper by Bouma *et al.,* (2004), which is included in the worked example Dutch Marine Habitats Classification.pdf.

In France the **ZNIEFF-MER** classification (Dauvin *et al.,* 1994) follows a similar approach to classification and level of detail to that used in Britain and Ireland (Connor *et al.,* 2004). The French classification has been extensively used in the REBENT programme (www.rebent.org).

In the western Atlantic, several different marine habitat classifications exist and the reader is directed towards Green *et al.,* (1999), Valentine *et al.,* (2004) and Madden *et al.,* (2005) for further details.

Links to resources

MNCR_04_05_introduction.pdf

EUNIS habitats correlation table.pdf

Dutch Marine Habitats Classification.pdf

Links to websites

http://www.jncc.gov.uk/MarineHabitatClassification

http://www.searchMESH.net/metadata

http://www.rebent.org

How are the 'legal and policy habitats' related to EUNIS?

The EC Habitats Directive and the OSPAR Convention have both developed lists of habitat types requiring conservation and protection. These lists are not classification schemes *per se*, but in both cases, the habitats listed have been correlated with types defined in the EUNIS classification (see EUNIS habitats correlation table.pdf). They are important instruments in directing survey, mapping and management effort; as such many studies have focussed specifically on surveying and mapping the listed types (particularly for the Habitats Directive).

Links to resources

EUNIS habitats correlation table.pdf

What is the size of a habitat?

Scale is a major consideration throughout the mapping process and, although marine habitat units are often described from observations and/or samples taken at a point location on the seabed, the minimum size of a marine habitat unit is generally taken to be about $25m^2$. At this size, a habitat unit is easy to visualise and is suitable for many forms of observation from direct visual observation of diver/shore surveyor, through video/ROV to high resolution acoustic techniques. It is referred to as the minimum habitat size. Any community of species occupiing a smaller area, or a particular niche within the habitat area (e.g. rock pools, isolated boulders on sediment plains), is considered to be an attribute of the habitat. This size convention was devised on pragmatic grounds with habitat mapping in mind.

Printed maps in common use such as topographic maps of the terrestrial environment (e.g. UK's Ordnance Survey maps) and navigational charts, are typically printed at map scales around 1:10000, 1:25000 or 1:50000. In simple terms, the larger the second number, the larger the geographic area covered for the same size piece of paper. A square of 5m x 5m equates to a square of 1mm x 1mm on a paper map drawn to a scale of 1:5,000! This is would be too small to plot on these 'typical' maps in common use and therefore a habitat would need to cover a larger area before it could be plotted. Thus, the minimum habitat size is NOT the same as the minimum unit area that can be represented on a map; this minimum is termed the smallest cartographic unit (SCU). These concepts of area, scale and level of habitat detail are explained in the later section discussing how the determine what to map (see the section What do you want to map?).

There is no upper limit on the area that a single habitat can cover and some habitats may cover many 100's of km^2, for example offshore sediment plains. Both from an ecological perspective and a physical habitat perspective, it is possible for habitats to vary enormously in extent from a few square metres to 10s or even 100's km^2 before their character changes sufficiently to warrant defining and then mapping a separate habitat type. Habitat size tends to be small in intertidal areas (because environmental conditions change rapidly over small distances) but very large in deep seas where environmental conditions are stable over wider areas.

It is not hard to envisage complications in applying minimum habitat sizes to real situations that arise because of fine-scale complexity and heterogeneity. These factors need to be considered when aggregating data into units of area that can be mapped at any particular scale <Link to later Section on scale>.

It is important to note that habitat size does not necessarily increase as habitat descriptions become more general: for example a habitat such as *intertidal rock with seaweeds* could occur as small isolated outcrops on a large sandy beach that may comprise a very narrowly defined habitat specifying the key species and sediment grain size (*Lanice conchilega* in littoral sand). . Thus broadly described habitats can be found in small patches and habitats may not be the best units to describe very large areas. This notion of scale in defining seabed features has been extended into the concept of marine landscapes (also referred to as seascapes). These are large physiographic features such as estuaries or seamounts, and large areas of seabed defined mostly on their topographic character such as offshore sediment plains. Marine landscapes are discussed further in the section Landscapes and habitats – different approaches to classification later in the MESH Guide.

Links to other sections

What do you want to map?

Landscapes and habitats – different approaches to classification

Boundaries and continua in the marine environment

To define and map habitats is to place boundaries on them, to distinguish one from another either in definition or on a map.

The reality of the marine world is much more complex, such that there are often no distinct boundaries, just a gradual change in character over distance. In some cases, there are strong physical boundaries, such as when a rocky reef rises from a sediment plain, but more often there is a gradual transition, say from one sediment type to another (e.g. sandy mud to muddy sand). Similarly, there may be distinct biological boundaries, such as a kelp forest abruptly changing to an animal-dominated community with depth due to reduction in light levels. However many changes in community are gradual, along more diffuse gradients in environmental conditions (e.g. wave exposure and tidal currents). The lack of distinct boundaries presents real practical problems for habitat mapping and in establishing robust habitat classification schemes.

Defining habitats at differing levels of detail – a hierarchy

Mapping of habitats necessitates defining their character at a certain level of detail, and thus expecting a particular level of consistency in character over the surveyed extent of the habitat. This can be undertaken at various levels, leading to the notion of hierarchy in defining habitats. For instance, in shallow rocky habitats an upper zone can be defined which supports very dense kelp (a forest) and a lower zone with more sparse kelp (a park). The two zones (kelp forest and park habitats) can be more broadly defined as 'kelp habitat', thus defining a hierarchy in habitat definitions and mapping units. This kelp zone could be further aggregated with other seaweed communities to define an even broader 'seaweed on rock' habitat.

Defining habitats at various levels of detail can be an outcome of the survey techniques used (i.e. the techniques determine how coarse or fine the definitions in habitat type are) or it can be part of a habitat classification scheme in which it is helpful to have both finely- and broadly-defined habitats (see the sections What is a habitat classification scheme? and What classification schemes are available?). A consequence of defining habitats in less detail is that one would expect greater variation in character within each type defined, and that they should cover larger areas than their more finely-defined component sub-types.

Links to other sections

What is a habitat classification scheme?

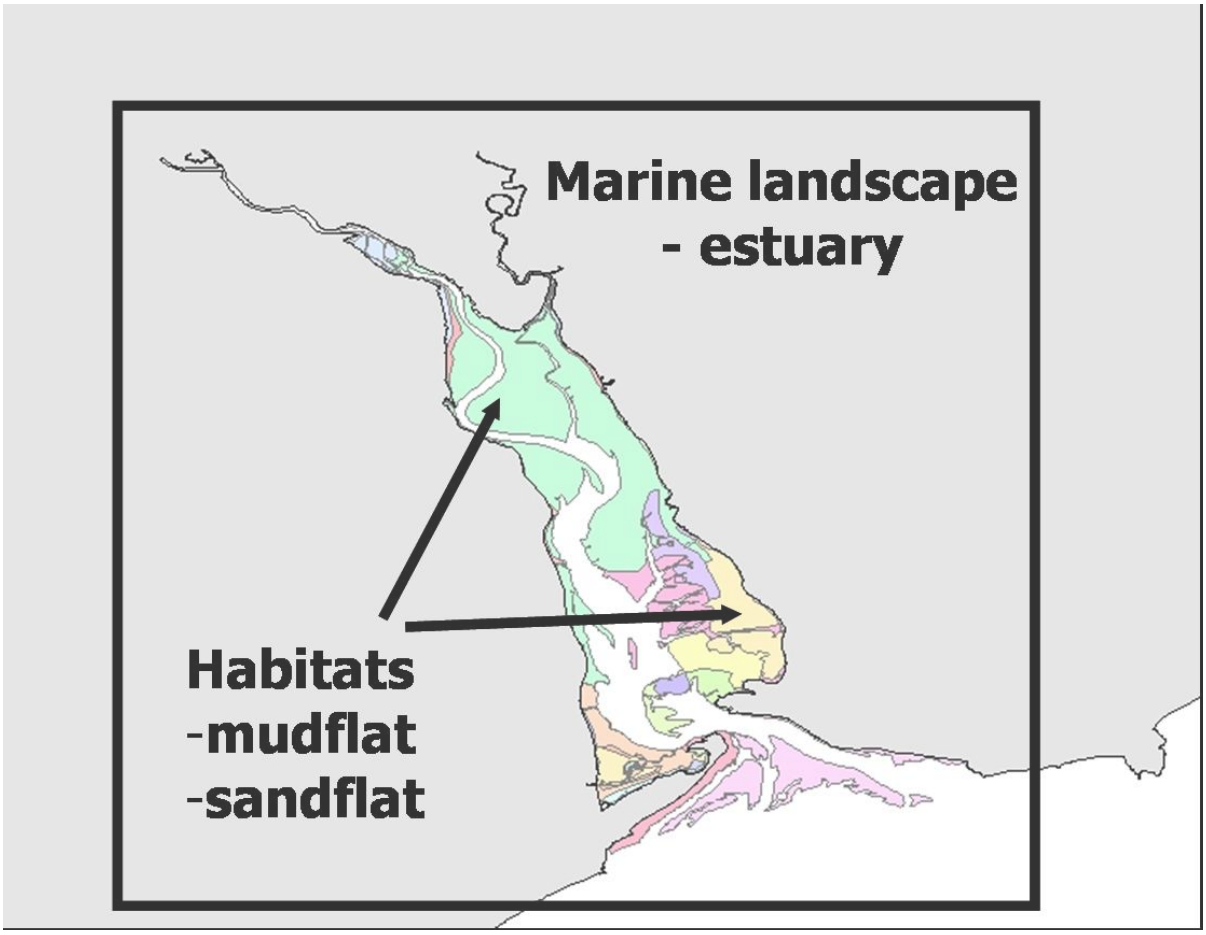
What classification schemes are available?

Landscapes and habitats – different approaches to classification

Classification of the marine environment can be approached in a number of ways and at a variety of levels of detail, depending on the purpose of the classification, the methods used and the data available. For environmental management purposes, it is important to classify the marine environment in an ecologically meaningful manner in order to support an ecosystem-based approach to management.

For the seabed, classification has typically been achieved through characterisation of seabed features by habitat type. This approach to classification is reflected in various national and European schemes (see the section What classification schemes are available?).

The habitat approach to classification takes only limited account of broader patterns in seabed character, such as seabed morphology determined by major geological and hydrographic processes. Thus features such as seamounts and estuaries can be considered to occur at a scale above the habitat scale; each comprises a suite of habitat types in a more topographically-defined feature – at this level of classification, the features are described as marine landscape types and can be considered to be broadly equivalent to mountains, valleys, plains and rivers in the terrestrial environment. Each marine landscape type will comprise a series of habitat types, some of which are typical of (or specific to) the landscape type; additionally they may occur in a particular pattern (such as a zonation of habitats from the top of a seamount to the bottom). In addition, many habitat types can occur in several landscape types (for example, seagrass beds can occur in sealochs, bays and estuaries) – this means that the two approaches to classification are related to each other but cannot be fully integrated into a single hierarchical classification (Connor *et al.,* 2006). UKSeaMap_FinalReport_Annex7.pdf shows the relationship between habitats and landscapes. The following figure of the Exe Estuary, UK illustrates the habitat and landscape relationship.



A map of Exe Estuary, UK illustrating relationship between the marine landscape and habitat scales of classification

Whilst the habitat approach is most suited to detailed (fine-scale) classification of the seabed (including field surveying and habitat mapping), the broader classification of marine landscapes is particularly useful for wider management purposes, as management is often most easily applied at this scale (e.g. for a whole estuary), rather than a component habitat.

Given the topographic emphasis of the marine landscape concept, its application to the water column is less valid, as topographic distinctions cannot be applied to the water column. Nevertheless, the pelagic environment can be classified using hydrographic characteristics (such as temperature and salinity) in a way which is ecologically relevant. The outputs probably best equate to the habitat concept, albeit at a very coarse scale.

Links to other sections

What classification schemes are available?

Links to resources

UKSeaMap_FinalReport_Annex7.pdf

What do you want to map?

Understanding the core concepts of map scale and habitat detail is fundamental to the success of a habitat mapping project. Such knowledge is required by those commissioning mapping projects because it helps establish realistic expectations, by those planning field surveys so that the appropriate equipment is selected, and for those analysing data and drawing the maps so that the products meet the requirements of the end-user.

A habitat map shows the geographic distribution of habitat classes on the seabed. A map can be printed onto paper or displayed electronically on a screen. Regardless of the display medium, a map shows a defined and thus restricted geographic area of the seabed. Clearly establishing the geographic area of interest is fundamental to the success of a mapping project.

Representing a geographic area onto a display medium introduces the concept of map scale that is normally shown as the ratio of the size of the map to the size of the geographic area it depicts. An A4 page is approximately 20 cm wide by 30 cm tall (in portrait view). If this showed a map covering an area 2 km wide by 3 km tall (20,000 cm by 30,000 cm) – such as a small bay the scale would be 20:20,000 (30:30,000) or 1:10,000. Taking the opposite view, a feature shown on such a map that was 1 cm long would be 10,000 cm long, or 100 m, in the real world. If the same A4 map depicted and area 200 km by 300 km – a regional sea such as the Irish Sea its scale would be 1:1,000,000 with a feature 1 cm long representing 10 km in the real world.

A similar element of 'size' appears in the definition of a habitat: the minimum size of a marine habitat unit is generally taken to be about $25m^2$ (5m by 5m). 'Size' is also reflected in habitat classification schemes where is it is more commonly linked to 'biological detail'. At one end of the spectrum, habitat classes may represent a very high level of biological detail: for instance *a* Zostera marina *seagrass bed on coarse sediment*. At the opposite end of the spectrum, a habitat class may be very broadly defined – for instance, *rock with seaweeds* and could cover intertidal and subtidal areas of the seabed. Most often, detailed habitats cover relatively small areas of the seabed (10-100m dimensions); broadly defined habitats cover larger areas of the seabed (> 1km). When planning a habitat mapping project, setting out the level of biological detail that needs to be depicted on the final maps is fundamental to the whole mapping process because it has a very significant bearing on the choice of mapping strategy, the equipment required, the type of analysis needed and hence the overall cost of the project (see *What do I want to map?*).

Not surprisingly, there is a clear link between the geographic area to be mapped and the level of biological detail to be displayed when determining the effort (cost) required producing the map or maps. Setting out to map all the detailed habitats in the Irish Sea and print the results legibly on A4 paper would require a large number of pages! The following table shows the effort required to produce maps at either end of the area and habitat detail spectra, and introduces the common habitat mapping terms of 'broad-scale' and 'fine-scale' maps.

Effort related to area & detail		Habitat detail	
		Low	High
Area	**Large** **>100 km by 100 km**	Effort matches area to be surveyed: typical broad-scale survey	Very high effort demanding high level of resources: National survey program
	Small **< 20 km by 20 km**	Returns do not justify survey	Effort matches area to be surveyed: typical fine-scale survey

Effort (and funds) required for habitat mapping are related to a combination of map area and required level of habitat detail.

The two ends of the area/habitat detail range of mapping activities can be loosely termed 'fine-scale' and 'broad-scale' respectively.

Once you have clearly established the level of habitat detail required on the final map, the extent of the geographic area of interest, and secured the necessary resources to undertake the mapping work, you need to be aware of the different routes available to produce the final maps. The following section describes the main consideration when deciding how to map the habitats in your chosen area.

What is broad-scale and fine-scale habitat mapping?

Broad-scale and fine-scale maps are at the opposite ends of the area/habitat detail spectra and generally have very different uses. The techniques used for deriving these maps may be also quite different. Habitat mapping uses the term 'scale' in a generic manner to cover the complex interaction between area/size of features/habitat detail/type of mapping. Scale therefore helps to define the approaches to habitat mapping, although there is no fixed point along the scale spectrum where mapping changes from fine-scale to broad-scale: there is a wide range of scales between the two extremes where the objectives and methods adopted for creating maps overlap.

Nevertheless, consideration of the scale helps to focus the discussion on what is meant by habitat mapping.

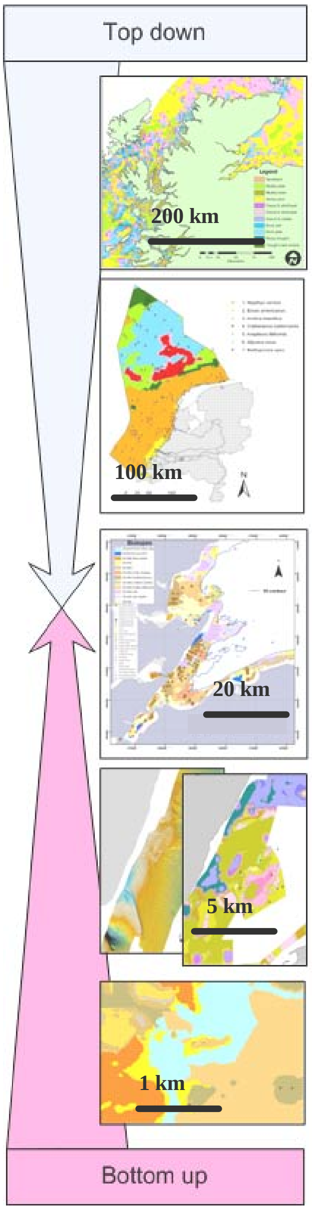
There are a number of key terms and concepts that must be explained to fully understand the fine-scale to broad-scale mapping spectrum:

- **Map scale and area**: the issues of scale and representation are central to any discussion on habitat mapping within the MESH project. Typically, printed habitat maps range in scale from small scale (where objects are represented as relatively small, e.g. 1:250,000) to large scale (objects shown relatively large, e.g. 1: 25,000). However, since the terms 'large' and 'small' scales are often confused, these are also referred to as broad-scale and fine-scale respectively, which will be adopted in this MESH Guide.
- **Process**: at the finest scale, remotely-sensed survey data and ground-truth samples are collected (usually from a single study) and interpreted for a particular purpose. Actual area surveyed is comprehensive (e.g. often exceeding 100% where multibeam sonar swaths overlap) using techniques chosen as appropriate to the survey of target habitats. Broad-scale mapping

may be entirely a desk-top process where many sources of data are amalgamated and transformed to derive input layers for modelling. Processes for intermediate scales may be (1) largely desk-top utilising data collected for a variety of purposes, (2) based on survey data collected over a long-term campaign or (3) be based on a commissioned survey but with incomplete coverage of remotely-sensed data and low density of ground truth samples with the gaps filled by interpolation.

- **Purpose**: fine-scale mapping provides a detailed description of the distribution of comprehensive range of habitats. There may be a need for a statistically robust map of the extent of and clearly defined boundaries between target habitats for monitoring purposes, often as part of a site management plan. Fine-scale maps may be compared one with another and to broad-scale maps. This perspective can be termed 'bottom-up'. Broad-scale maps summarise knowledge of broad trends in habitat distribution often in support of more strategic policy making or assessing the implementation of policy (e.g. assessing what proportion of the total national resource of a habitat of conservation interest is included in a suite of marine protected areas). Often, a broad-scale map has the general purpose of providing an overview of a large area to give context for more local data. From these perspectives, desktop mapping is often considered to be 'top-down'.
- **Resolution, accuracy and predictive power**: mapping at the finest scale aims for high accuracy and resolution. There may be a need to repeat the mapping at some future date and for the maps to have a level of statistical certainty to underpin decision making or management action. Broad-scale maps are only intended to show the **indicative** distribution of habitats (i.e. not to be taken too literally) with low resolution and accuracy, but with a moderately high confidence of the information shown on the maps.
- **Effort**: large areas are generally mapped at a broad-scale due to the effort required for comprehensive survey per unit area. However, it must be pointed out that this need not always be the case – a national mapping programme such as the Irish National Seabed Survey (http://www.gsiseabed.ie/) would map a large area in detail. A large area can be broken up into a number of smaller constituent areas and each mapped at a fine scale through a rolling programme of surveys over time. Small areas are normally surveyed at a fine scale since it would be expensive and rather pointless to mobilise a survey team only to undertake a perfunctory survey.

The following figure presents these key points in relation to the fine-scale to broad-scale mapping spectrum.



SCALE	PROCESS	PURPOSE	ACCURACY & RESOLUTION
>1:250,000	Modelling with the key universal physical factors which are derived from multiple sources of information often many stages removed from original survey data	Summarise knowledge of broad trends in habitat distribution to give context for finer scale information	Low resolution & accuracy, but broad trends robust and explanatory power stands up to scrutiny from scientific community and other users
1:100,000	Modelling with coverages & datasets from coordinated survey campaign	Broadscale prediction of distribution of major habitat types or key species	Statistically derived predictions that should be tested with stratified survey
1:50,000	Interpretation of incomplete coverages reliant upon interpolation	Indicative description of trends in distribution of comprehensive range of major habitats	Maps of modest accuracy but sufficient for spatial inventory as basis for further survey
1:25,000	Modelling & classification with single survey, comprehensive coverage	Detailed description of the distribution of comprehensive range of habitats	Accuracy measured and at least moderately high and with expectation of good predictive power of map
1:10,000			
1:5,000	Intensive survey using techniques selected for the detection of target habitats	Statistically robust map of extent and boundaries of target habitats	Surveys designed to be repeatable and statistically comparable

A summary of the main characteristics of habitat mapping across a range of typical scales

All habitat mapping shares the common objective of producing maps that are fit for their intended purpose. They should show the best estimate of habitat distribution based on the most appropriate existing data that are readily available, or through commissioning new surveys that are well designed to deliver the best data with the time and budget available. The purposes of habitat maps at opposite ends of the coverage spectrum are likely to be very different from each other, ranging from site condition monitoring and for new developments at the finest scale to strategic policy planning at the broadest scale. For some applications, we need to 'nest' maps at different scales to help understand different aspects of the environment.

Links to websites

http://www.gsiseabed.ie/

Nested maps of different scales

When maps of different scales for a particular area are brought together, the fine-scale maps will show the detail, whilst the broad-scale maps will show a more generalised distribution of the fine-scale habitats. If the maps from the two perspectives are accurate, there should be a high degree of correspondence between the two scales, i.e. the broader-scale map should show the habitat classes and their boundaries as matching those of the finer-scale map, but in a more generalised manner; for example some detailed habitat classes may be aggregated to a broader level in a habitat classification hierarchy, or some habitat polygons not shown as their dimensions are too small for a broader-scale map. However, it will often be the case that the broad-scale and fine-scale maps are derived from very different source data, and this can lead to a lack of correspondence of the habitat classes and their boundaries between respective maps. As new data become available to improve the quality and resolution of the maps, we would expect this lack of correspondence to reduce over time. In particular, this should happen as the more broad-scale maps are increasingly derived by generalising the fine-scale maps rather than being derive by modelling other physical data.

Nested maps are a special case of summarising information where a fine-scale map derived from a habitat survey lies within a broader-scale map which was derived from cartographic modelling. It is possible that the two maps will not match exactly because of the two completely different approaches used (top-down versus bottom-up). It is also unlikely that the cartographic model can be altered just to accommodate the nested survey. This situation brings out the very different purposes and predictive capabilities of the maps from the two scales and illustrates the difficulties which arise from using data at different scales.

This is likely to be a common situation in the MESH programme and it is worth expanding upon the nature of the differences and mismatches. There is a middle ground that has been left out (scale 1:25,000 – 100,000).

Clearly, the fine-scale map can be used to validate the broad-scale cartographic model, but it will be difficult to judge the significance of irreconcilable differences between the two, given the differences outlined above.

What are the smallest habitat areas you can map?

There are many answers to this question! As discussed in the section **What is the size of a habitat?**, habitats have no specific natural size, but the general advice for recording and/or sampling habitats in the field suggests using a minimum size of 5 m x 5 m (accepting that they will not be square). It must be remembered, however, recording habitats of this size in the field does not mean that the final maps will show such detail. There may need to be larger homogeneous areas of habitat before they can be drawn onto a map at the desired map scale due to basic cartographic rules (limitations) – see below. An equally important consideration is whether a remote sensor can detect habitats at this size; a sensor must have sufficient resolution to record habitat units at this minimum size – see below.

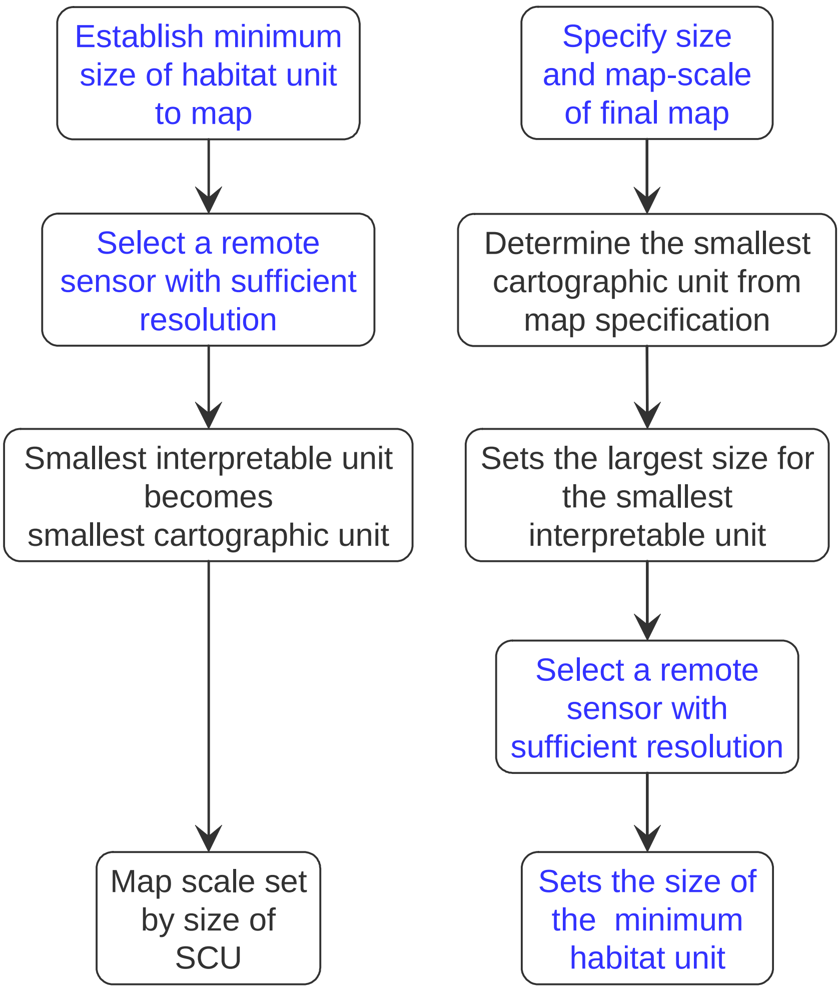
We normally think of resolution as the ability to separate and distinguish adjacent objects or items in a scene, be it in a photo, an image or real life. We often specify the resolution in terms of the linear size of the smallest features we can discriminate (often expressed in meters). But, contrast influences our ability to resolve between objects: if two items are the same colour, they may be hard to separate, but if they are sharply different in colour, tone, or brightness we can identify them more easily. When selecting a remote sensing tool for habitat mapping, it is clearly essential that you consider the capability of the tool in terms of its ability to both resolve spatial and textual differences in the habitats you wish to display on your final map. Data from remote sensors are normally viewed as images either printed (analogue format) or electronically as digital images. Images are composed of picture elements or pixels and where these images are linked to real world co-ordinates (geo-referenced), each pixel related to an area on the ground. The size of this area is determined by the spatial resolution of the sensor where modern sensors (on satellites, aircraft and ship-borne acoustic systems) can typically achieve spatial resolutions of less than 5m – see Section 0 for further technical detail

Once the imagery is collected by a survey, there are two common methods for discriminating features on the ground (seabed): manual interpretation or automated classification. If the interpretation is manual on analogue material (i.e. an image printout or a film), the interpreter drafting polygons will tend to only consider drawing around units whose smaller dimension is larger than 3 mm on the printed document (a surface area not smaller than 9 mm²). There is no absolute rule for this minimum size, it is a 'rule of thumb' selected for the mere matter of drafting comfort. This is referred to as the Smallest Interpretable Unit or SIU. Remote sensors do have inherent errors introduced through their design and operation – called system 'noise'. Consequently pixels are not meant to be viewed individually since its value could easily be an artifact due system error. When pixels form clusters with similar values, the information they display is more reliable and more likely to be related to a unit on the ground. These clusters form the SIU of a classified image that often has similar dimensions to the SIU from manual interpretation. Either way, it is the SIU that must be considered when selecting the most appropriate remote sensing tool to resolve the target habitat types of the mapping project.

Cartography is a mixture of aesthetics and science. A cartographer generally has to compromise between the elements of map scale, map detail and ease of use of the map. Too much detail will render a map confusing and hard to read; too little detail will reduce the value of a map. In general, the smallest shapes drawn on maps – the Smallest Cartographic Unit (SCU), are approximately 1-3mm depending on the actual shape (point, line, or polygon). A basic 'rule of thumb' currently adopted in "thematic cartography", i.e. a cartography meant to represent only surface elements on a map, suggests that polygons smaller than 9 mm² are not drawn on a map; note that in the particular case of the terrestrial habitat maps for the CORINE Land Cover Project (http://reports.eea.europa.eu/COR0-landcover/en) the smallest unit chosen was 25 mm². In our particular case of adopting 5m by 5m habitat as a minimum size, showing a 25 m² habitat unit into a visible unit of 9 mm² on paper means a scale of roughly 1:2,000. This is therefore the bottom line scale where one is sure to see all habitats units; maps drawn at a coarser scale will not be able to show habitat units recorded at this size. A more detailed explanation of cartographic limitations is provided in the sections Cartographic limitations [for vector maps and Limitations of raster thematic mapping?.

Once remote images have been interpreted to show habitat classes, the cartographer has to create the final habitat map to show the desired level of detail. At this point, how the Smallest Interpretable Unit from the image is related to the Smallest Cartographic Unit on a map will depend on the aim of the mapping project and the specification of the final map. Simplifying many concepts and skipping over a range of complex problems and decisions, there are two basic routes to depending on the way the mapping requirements are expressed by those commissioning the work (see the figure below):

- If they require that individual habitat units (of so many square metres) be mapped then the left-hand path can be followed, which gives guidance successively on the appropriate remote-sensing tools and the appropriate scale for the resultant map (SIU and SCU being fixed parameters).
- Another way of specifying the work could be "to map a given area on scale 1:10,000 with as much habitat detail as possible". In this case, the right-hand sequence in the following figures applies. For a map-scale of 1:10,000, the SCU is 30 m in dimension (900 m²) and so the remote sensor's resolution should be at least 5 m; there is a rule of thumb that suggests a sensor's resolution should be about a fifth of the required SIU. Where the SIU is smaller than the SCU, the cartographer will have to merge individual units to create habitat units larger than the SCU – a process called generalisation that can introduce a new set of problems (see the section Scale, resolution and the SCU)).



A summary of how specifying the mapping requirements will influence the specification of the survey resolution and the final map scale. Text in black indicates fixed parameters; text in blue indicates where the user has a degree of choice.

Links to other sections

Cartographic limitations [for vector maps

Limitations of raster thematic mapping?

Scale, resolution and the SCU

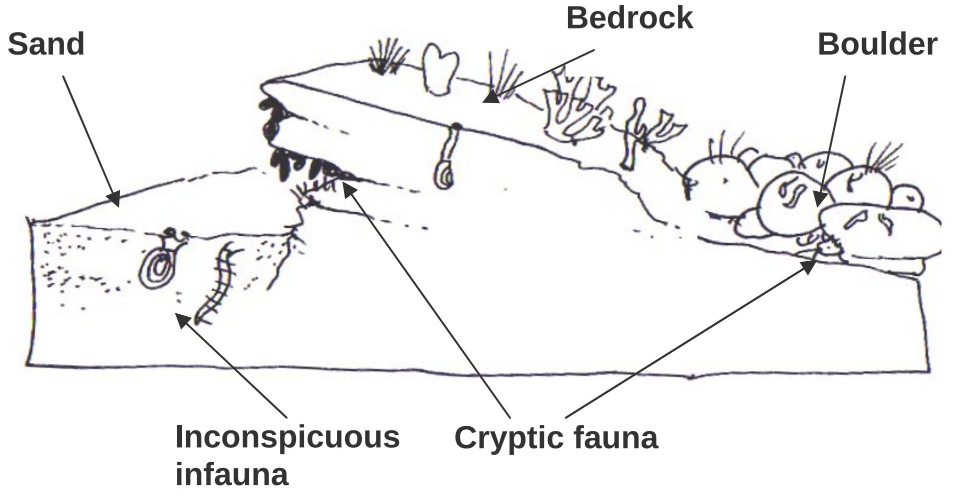
Links to websites

http://reports.eea.europa.eu/COR0-landcover/en

Technical reasons why some habitats may not be mapped

Habitats (substratum and other environmental features together with biota) can be defined by the predominant conspicuous biological and physical characteristics. However, in the figure below, this is complicated by three issues:

- multiple habitats occur in a small area – they are mixed at a fine scale;
- the characterising biota of a sediment habitat mostly live within the sediment (infauna) and not readily 'visible', and;
- the biodiversity of rocky habitats may lie mostly in small niche habitats that are hard to sample remotely (under rocky ledges, under boulders, bored into the rock).



These issues are going to have an enormous impact on a mapping programme and the any application of maps to provide answers to questions on biodiversity and the occurrence of rare species that might be crucial to policy implementation and subsequent management of human activities.

Three scenarios are depicted in the figure below which illustrates some of the main problems for habitat mapping.

1. The illustration on the left represents infaunal-dominated soft sediment habitats. It may be difficult to detect and map these habitats using remote sensing and sampling because:-
    a. Many of the sediment properties that affect reflectance will not be measured.

Close

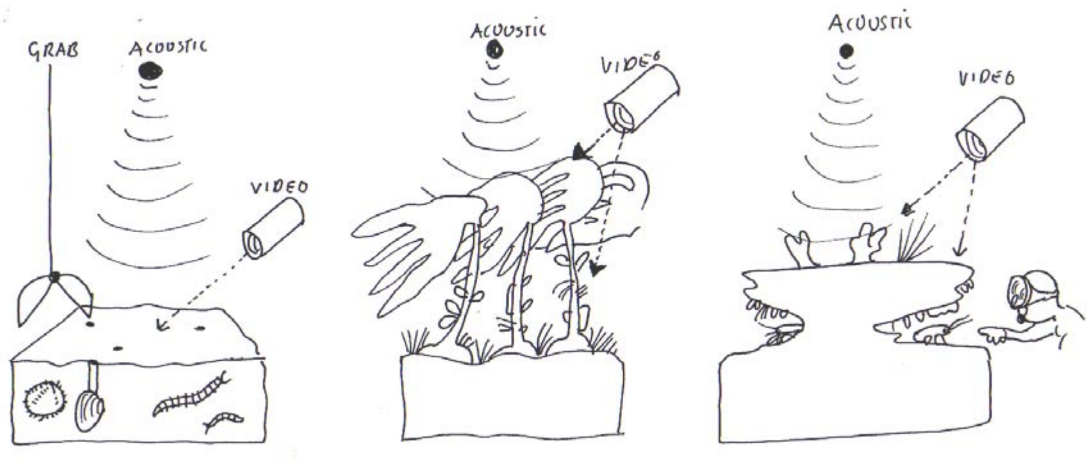
b. The sediment acoustic properties may of may not be affected by the activities of infauna.

c. Sampling may not adequately represent the biota. Grab sampling will reveal some of the infauna, but since the scale of observation (typically $0.1m^2$) we cannot be sure if the samples are really representative of the wider area (unless a number of replicates are taken) and it is likely that the more dispersed megafauna will not be sampled. Video (in clear water) might sample a larger more representative area, but most of the infauna will be hidden from video.

Thus, the links between observed sediment properties and acoustics may be inconclusive. Even if these are adequate to map sediment type, establishing links between infauna to acoustics may be uncertain. The net result is that for many sediment habitats we might be able to map sediment type with some success, but mapping habitat defined by infauna may be much less successful.

2. In the centre illustration, the conspicuous biota may have a marked and characteristic effect on the acoustic remote sensing and video well able to observe the biota. Mapping the habitats might be successful. However, positive identification of the kelps may not always be possible from observations of the canopy and the habitat will be identified only to a kelp life form. The important biota below the canopy might also be hidden. Thus, the resulting habitat map may not be able to distinguish between different types of kelp habitat with certainty.

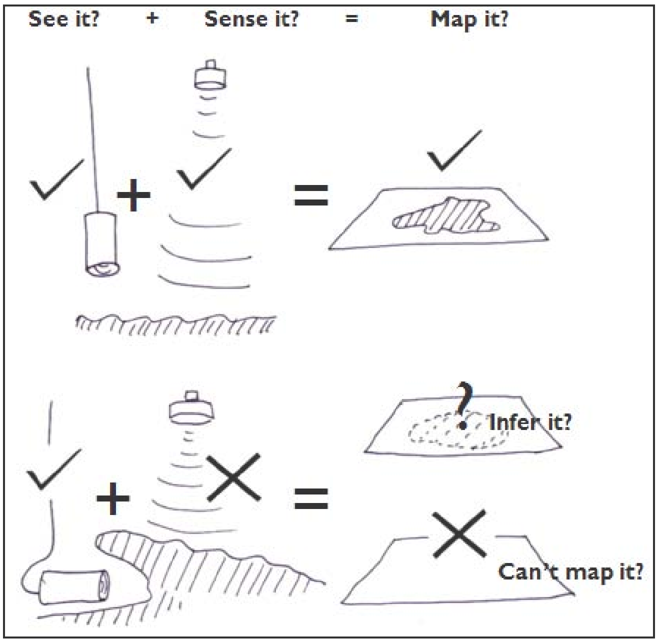
3. Lastly in the illustration on the right, the acoustics might be able to detect the varied rocky habitat with confidence, and these features observed with a video. But the majority of the biota might be hidden and important information on biodiversity obtained only from a limited number of dive stations.



Illustrations to show how sampling and recording techniques may only detect part of a seabed habitat

Clearly, choosing the right sampling tool will assist the mapping process, but there will still be limitations as to what mapping can achieve technically that must be appreciated by end-users to avoid false expectations from the habitat map. It may be necessary to accept that the only way to map data on diversity will be using point records superimposed on a broadly defined habitat map.

In summary, if you can see the defining habitat features and you can detect them, then there is a good chance you can map the feature. If you can see it, but it is hidden in some way from the remote sensing tool, then ***either*** you can infer the distribution from other linked habitat features ***or*** you can't map it as a complete habitat coverage (see following figure)!



A summary of the fundamental considerations about the nature of any habitat you wish to attempt to map

Resolution in remote sensing terms

It is important to understand how a remote sensing tool operates in order to appreciate its ability to detect features - such as habitats - on the seabed (in intertidal or subtidal areas). There are many excellent texts and websites explaining all the technical aspects of remote sensing; for example Green *et al.,* (1999) describe the use of satellite and airborne remote sensors for marine mapping in tropical waters (http://www.unesco.org/csi/pub/source/rs.htm). The following text is based on information available on the US' NASA website (http://rst.gsfc.nasa.gov/) with some definitions taken from Wikipedia (http://en.wikipedia.org).

Remote sensors measure and record the magnitude and frequency of reflected energy from an object where the 'energy' is generally either electromagnetic radiation (light) or acoustic (sound). Remote sensing devices mounted on aircraft and satellites normally use imaging sensors that measure reflected energy from objects under surveillance; the mostly commonly used sensors for underwater detection use acoustic systems although the results are often presented as images. Imaging sensors fall into two general categories: active sensors and passive sensors. Passive sensors monitor only the natural solar reflected light or electromagnetic energy from an object and form the majority of the airborne and satellite based sensors in use today. Active image sensors provide their own energy which is transmitted to the object and then reflected back to the sensor. Acoustic systems, RADAR and LIDAR (based on a laser) are all active sensors.

Early remote sensing devices recorded photographic images on film (taken by cameras) or traces printed onto paper rolls (sonar devices). Both routes created an image in analogue format. These images were fixed and could not be subject to very much manipulation (correction, change of contrast or colour etc); more recently, they can be converted into an electronic digital format for limited manipulation. Most modern sensors now record their information in digital format, often as digital images. A digital image is made up of numbers, which represent image attributes such as brightness, colour or radiated energy frequency wavelength, and position location for each point or picture element in the image. The smallest sized picture element on an image is called a pixel; a digital image is made up of pixels arranged in rows and columns commonly known as a raster image. The dimensions and the information content of these pixels are both aspects of the resolution of the image.

Resolution has a popular meaning but is best defined in a technical sense. We normally think of resolution as the ability to separate and distinguish adjacent objects or items in a scene, be it in a photo, an image or real life. We often specify the resolution in terms of the linear size of the smallest features we can discriminate (often expressed in meters). But, contrast influences our ability to resolve between objects: if two items are the same colour, they may be hard to separate, but if they are sharply different in colour, tone, or brightness we can identify them more easily. Remote sensors measure differences and variations of objects that are often described in terms of three main resolutions, each of which affect the accuracy and usefulness of remote sensors to habitat mapping.

- **Spatial resolution** describes the ability of a sensor to identify the smallest size detail of a pattern on an image. In other words, the distance between distinguishable patterns or objects in an image that can be separated from each other and is often expressed in meters.
- **Spectral resolution** is the sensitivity of a sensor to respond to a specific frequency range (mostly for satellite and airborne sensors). The frequency ranges covered often include not only visible light but also non-visible light and electromagnetic radiation. Objects on the ground can be identified by the different wavelengths reflected (interpreted as different colours) but the sensor used must be able to detect these wavelengths in order to see these features.
- **Radiometric resolution** is often called contrast. It describes the ability of the sensor to measure the signal strength (acoustic reflectance) or brightness of objects. The more sensitive a sensor is to the reflectance of an object as compared to its surroundings, the smaller an object that can be detected and identified.

When selecting a remote sensing tool for habitat mapping, it is clearly essential that you consider the capability of the tool in terms of its ability to both resolve spatial and textual differences in the habitats you wish to display on your final map.

Links to websites

http://rst.gsfc.nasa.gov/

http://en.wikipedia.org

Limits to interpretation

Even if it is possible to detect a feature, there may be other reasons why it might be difficult to show this information as habitat polygons. For example, the original habitat class information might be at a very low level in the EUNIS system (e.g.

showing local variants of sub-habitat classes) which might mean that there are a very large number of classes in the survey area many of which have been sampled only once or twice. It might not be possible to interpret the remotely-sensed data using this number of classes because (1) there are too few samples of each class to be sure of the interpretation and/or (2) the classes produce very similar and overlapping signatures from the remote sense data and cannot be discriminated successfully. In these cases a more generalised habitat map showing fewer classes might be more appropriate. These limitations should be considered at an early stage in the planning process. Is it really necessary to map at a high resolution and level of detail to address aims of the project, given the likely high costs and complex analysis involved?

Thus, broad scale maps may need to be simplified from fine-scale data layers. Simplification can introduce errors when an analyst has to decide how best to combine classes that occur in mixtures (of small clusters or isolated pixels) at a scale that cannot be represented on a map.

Cartographic limitations [for vector maps]

Cartography is a mixture of aesthetics and science. There is generally a compromise between map scale, map detail and ease of use of the map. Too much detail will render a map confusing and hard to read; too little detail will reduce the value of a map. The following table relates object size on a map (in mm) to the real size of objects at different map scales, remembering that polygons with dimensions of 2-3 mm are probably the lower limit of what can be represented on any (printed) map. It is clear that even at a fine scale objects of less than 10 m (and advisably less than 20 m) cannot be shown on a map.

Map object size (mm)	Real size (m) represented at map scale:			
	1:10,000	1:25,000	1:50,000	1:100,000
1	10	25	50	100
2	20	50	100	200
5	50	125	250	500

A square polygon with these dimensions is the smallest habitat that can be displayed on maps at a range of scales and is defined as the smallest cartographic unit (SCU). These must be considered in the planning stages of a survey since they represent the maximum resolution and level of detail that should be expected in the final habitat map. The SCU is not the same as the maximum resolution of the remote sensors (which might be much finer) nor does it strictly equate to accuracy and precision of the map (which might be much coarser).

The SCU as indicated in the Table relates to polygons and would not normally be squares with those dimensions, but irregularly shaped. The situation with raster maps is somewhat different. It is possible to reproduce maps with a much smaller pixel size (a pixel is really a very small square usually without the sides marked as hard lines) than a drawn polygon with its well defined boundaries.

A given pixel size from a fine-scale map will equate to a smaller area of the sea floor than a pixel from a broad scale map. The pixel size as printed on a map, therefore, determines the map's resolution. The table below is typical of the view of resolution of maps as defined by cartographers. It shows the equivalent real-world dimensions of pixels of three printed pixel sizes (0.1mm, 0.25mm and 1mm) for a range of scale. This can be used to set the limitations to resolution of a raster image.

	Resolution (dimension on map)		
	Fine (0.1mm)	Medium (0.25mm)	Coarse (1mm)
Scale	Real-world dimensions (m)		
1:5000	0.5	1.25	5
1:10,000	1	2.5	10
1:25,000	2.5	6.25	25
1:50,000	5	12.5	50
1:100,000	10	25	100
1:250,000	25	62.5	250

However, this does not mean that raster images have a higher definition than vector polygon maps. This is because pixels are not meant to be viewed individually. A single isolated pixel has little meaning on its own. When pixels form clusters with similar values, the information they display is more reliable. Areas with a speckled appearance due to variability between neighbouring pixels are viewed as heterogeneous areas. It would be wrong to assume each pixel class is accurately located. Thus, the SCU is roughly equivalent for polygons and *clusters* of pixels.

Areas mapped

Map scale	Area covered by SCU ($4mm^2$)	Printed map area for real-world areas of :						
		$1km^2$	$10km^2$	$100km^2$	$1000km^2$	$10,000km^2$	$100,000km^2$	$1,000,000km^2$
1:2,000	16 m^2	$0.25m^2$	$2.5m^2$	$25m^2$	$250m^2$	$2,500m^2$	$25,000m^2$	$0.25km^2$
1:5,000	$100m^2$	$400cm^2$	$0.4m^2$	$4m^2$	$40m^2$	$400m^2$	$4000m^2$	$40,000m^2$
1:10,000	400 m^2	$100cm^2$	$0.1m^2$	**$1m^2$**	$10m^2$	$100m^2$	$1000m^2$	$10,000m^2$
1:25,000	2,500 m^2	$16cm^2$	$160cm^2$	$0.16m^2$	$1.6m^2$	$16m^2$	$160m^2$	$1,600m^2$
1:50,000	10,000 m^2	$4cm^2$	$40cm^2$	$400cm^2$	$0.4m^2$	$4m^2$	$40m^2$	$400m^2$
1:100,000	40,000 m^2	$1cm^2$	$10cm^2$	$100cm^2$	$0.1m^2$	**$1m^2$**	$10m^2$	$100m^2$
1:250,000	0.25 km^2	$16mm^2$	$1.6cm^2$	$16cm^2$	$160cm^2$	$0.16m^2$	$1.6m^2$	$16m^2$
1:500,000	$1km^2$	$4mm^2$	$40mm^2$	$4cm^2$	$40cm^2$	$400cm^2$	$0.4m^2$	$4m^2$
1:1,000,000	$4km^2$	$1mm^2$	$10mm^2$	$1cm^2$	$10cm^2$	$100cm^2$	$0.1m^2$	**$1m^2$**

For ISO paper sizes:

- an A4 sheet is 624cm² (0.06 m²)
- an A3 sheet is 1250cm² (0.1 m²)
- an A2 sheet is 0.25 m²
- an A1 sheet is 0.5 m²
- an A0 sheet is 1 m²

Limitations of raster thematic mapping?

When the smallest habitat size deemed necessary to record in a given survey has been decided, it is a matter of selecting a remote-sensing tool that can resolve these habitats on the seabed. The sensor's resolution (see the section Resolution in remote sensing terms) should be sufficiently high that the number of "pure pixels" is much larger than that of peripheral ones, thereby minimizing the error in surface area computation. As a rule of thumb, the spatial resolution should be in the order of a fifth of this smallest habitat size. Considering a 5 m by 5 m habitat unit, a sensor with a spatial resolution of 1 m will ensure that in the worst case 16 pure pixels (16 m²) are recorded out of 25, hence an error of at the most 30%. This 'rule of thumb' is only valid in clear-cut cases where colour (radiometry) prevails, in other words the ground unit is relatively homogeneous in terms of its colour and it is clearly contrasted against its surroundings. If texture is present within the unit rather than colour (e.g. small rock-pools distributed within a rocky substrate unit seen on an aerial photograph) then a higher resolution is advisable to bring it out. At present many remote-sensing tools offer this level of resolution (spatial, spectral and radiometric). In particular all airborne imagers and Lidar sensors have such resolution and also for sidescan sonar and of multibeam sounders in reasonably shallow waters (less than 100 m). Some of the modern satellites (Ikonos, Quickbird) are also capable of achieving such resolution.

Once the imagery is collected by a survey, there are two common methods for discriminating features on the ground (seabed): manual interpretation or automated classification. If the interpretation is manual on analogue material (i.e. an image printout or a film), the interpreter drafting polygons will tend to only consider drawing around units whose smaller dimension is larger than 3 mm on the printed document (a surface area not smaller than 9 mm²). There is no absolute rule for this minimum size, it is a 'rule of thumb' selected for the mere matter of drafting comfort. This is referred to as the smallest interpretable unit or SIU.

Where automated image classification is used to produce a "thematic map" of the ground, each individual pixel of the image will be assigned to a class that would equate to a habitat type if the image is processed to show habitats. Remote sensors do have inherent errors introduced through their design and operation – called system 'noise'. Consequently pixels are not meant to be viewed individually and a single isolated pixel has little meaning since it could easily be an artifact due system error. When pixels form clusters with similar values, the information they display is more reliable and more likely to be related to a unit on the ground. These clusters form the SIU of a classified image. Nevertheless, some areas may still have a speckled appearance due to the variability in values between neighbouring pixels and are best viewed as heterogeneous areas. Since pixels in a classified image are grouped in this way, the SIU is roughly equivalent for manually drawn polygons and automatically classified *clusters* of pixels in raster images. Similarly to working on an "implicit image" (e.g. an aerial photograph printout) as above, if an interpreter was to manually interpret a classified image in pixels (by drawing around distinguishable features), he would zoom in until losing visual comfort which in practice implies about 1 pixel to 0.5 mm. According to the principles set out above, after the classification is complete it is recommended to filter units made of less than 16 pure pixels as non-representative and to dissolve them into the surrounding class.

After the interpretation phase, it is the visual comfort of the map reader that is the main driver when it comes to representing these interpreted units (polygons or pixel clusters) on a map. When dealing with raster images, visual comfort means a non-steppy aspect to lines, when dealing with polygons, it means no tiny polygons that appear as a dot. To meet these visual requirements, a size of 9 mm^2 is really the smallest visible unit that should be represented on a map. It is referred to as the smallest cartographic unit (SCU). In the particular case where a number of these smaller units are close neighbours forming a mosaic appearance on the image, if the mosaic occurs regularly, it may be appropriate to create a 'mosaic' class that can be allocated a uniform appearance to improve the overall visual appearance of the map. Where the 'close neighbours' are closely related habitat classes, creating a mosaic class might be the same as moving to a broader habitat class in a classification hierarchy. Where the 'neighbouring classes' represent quite distinct, unrelated habitats, the mosaic habitat creates a separate issue to do with the suitability for mapping of the habitat classification employed.

Links to other sections

Section Resolution in remote sensing terms

Scale, resolution and the SCU

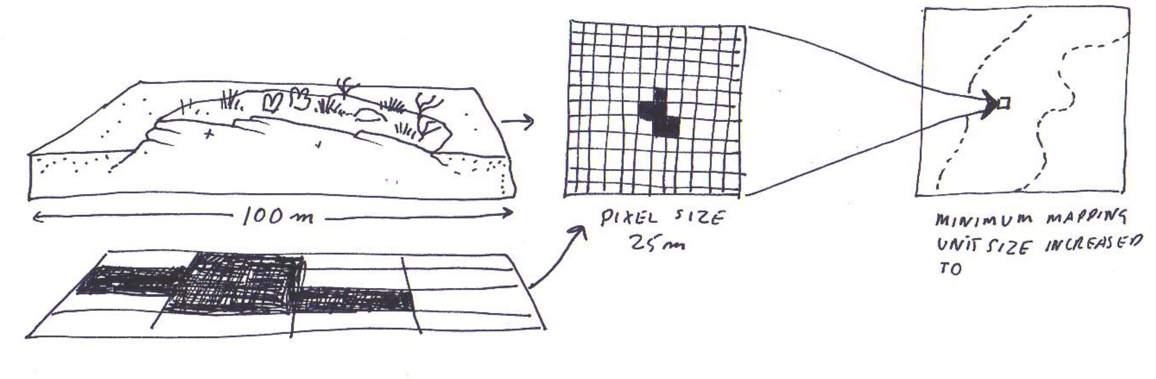
It is often assumed that the SCU reflects the level of precision and accuracy of the map. However, just because a map is printed at a high resolution does not mean the precision and accuracy of the map is correspondingly high. High resolution printing can be adopted purely for cosmetic reasons – the maps look better. It is often unrealistic to expect the position of habitats to have the corresponding level of precision. In reality the confidence of boundary position may be considerably less precise than. The map-maker chooses the resolution that looks bests and assumes that the viewer will understand that the distribution is meant to be indicative only.

Applying strict accuracy measuring techniques (see *How good is my map?*) will mean judging the success of a map against expectations far beyond those of the map-maker.

At a fine scale, the combined errors of the mapping techniques and analysis will set the absolute lower limits to the resolution of a map, assuming that a suitable map scale is chosen to show these sized units. For example, an area of sea floor with dimensions of 0.5m could be shown as a small pixel of 0.1mm at a scale of 1:5000. But, the reliability of an isolated pixel should be questioned. Some form of generalisation of this high resolution data is required to turn the data into more reliable information. That means averaging pixels and weighting the map towards clusters rather than individual pixel values. However, there is always the risk of losing valuable information through generalisation.

This is an issue of increasing importance as maps become more broadscale. It would seem reasonable to assume that a fine-scale map is accurate and precise, but that the purpose of broad scale maps is to summarise information usually at the expense of detail. Thus, (in general terms) fine-scale maps show as much detail as accurately as possible, and broad scale maps show broad trends.

In the figure below a small rocky reef with some rare and important soft corals occur on a sediment plain. This can be mapped as a small cluster of pixels each representing 25m on a map at a scale of 1:10,000 (for example). However, if the habitat map is of a moderately large area and the map is reproduced at a scale of 1:50,000, then this group of pixels will be vanishingly small. Is the reef important or not? If the occurrence of the reef is considered important, then it must be represented as a point occurrence overlying the more general, lower resolution habitat map.



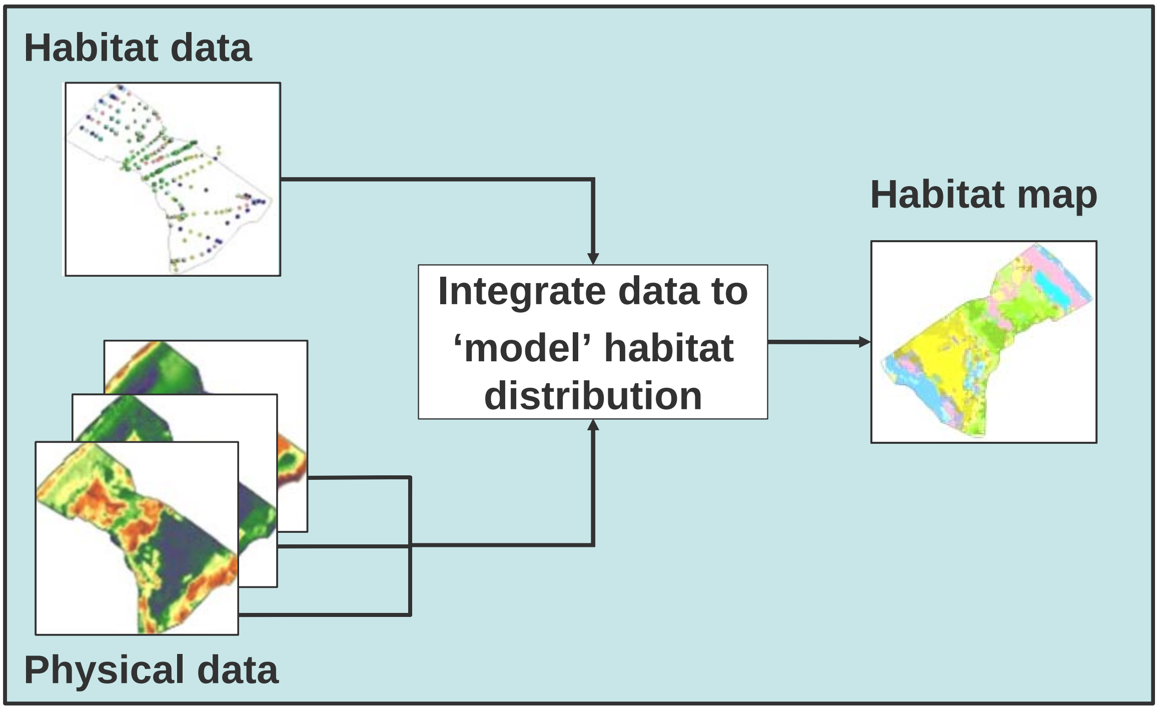
This illustrates the awkward decisions that need to be made about mapping: the purpose of mapping project must be matched to the size and environmental conditions of the site, the appropriate techniques and their limitations, the deployment strategy that can be afforded and cartographic limitations.

Links to other sections

How good is my map?

How do you map habitats?

The MESH Project is promoting a habitat mapping process whereby habitat maps are derived from integrating a continuous coverage of the physical properties of seabed (intertidal or subtidal) with observations of the habitats present at discrete locations as summarised in the following figure (repeated from earlier).



A summary of the habitat mapping process. It is important to remember that the final map is a *prediction* of the distribution of habitats.

Earlier sections have described some of the key questions that need answering when commissioning a habitat mapping project: Is the size of area to be mapped large or small? What level of detail do I need (very coarse habitat types or much fine detail)? What level of resources are available (time/funds/data/equipment)? Answers to these questions will shape the overall habitat mapping process to be adopted. When it comes to actually undertaking the work, the main differences in the approach taken relates to the source of the physical and habitat data. Habitat maps can be derived from either existing data using desk-based studies, or new data from bespoke field investigations, or a combination of both approaches.

In this section, the following issues are introduced:

- **Survey or modelling**: depending on the answers to the strategy questions above, you may need to undertake a desk study to model habitat distribution or to undertake new field survey to collect your own data to map the area of interest.
- **Remote sensing and ground-truthing**: most mapping studies are best undertaken by integrating remote-sensing data, which provides full coverage information of the seabed, with ground-truthing data that validates the features identifiable in the remote-sensing data.
- **Types of data are needed**: whether surveying or modelling, you need to understand which types of data will be needed to map your study area. These

data relate to the biological, physical and environmental parameters which together determine the types of habitat present in the area.

A habitat map is the culmination of a complex process that is far from error-free! All elements have their strengths and weaknesses and those commissioning habitat mapping projects must be aware of some of the limitations and sources of error present in the final maps.

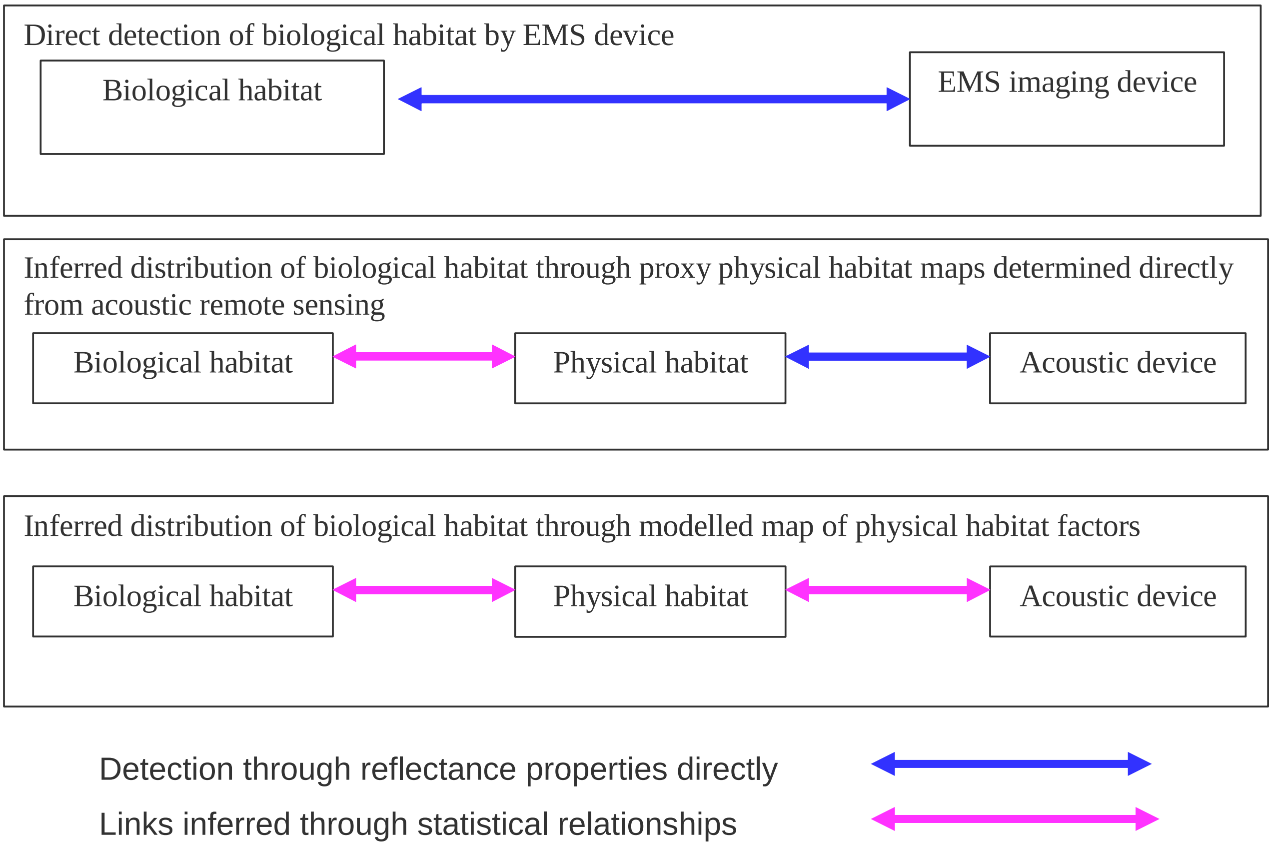
What are the approaches to habitat mapping?

Remote sensing techniques that capture the reflectance of the electromagnetic spectrum (EMS), such as satellite images, aerial photography and, indeed, the eye, literally see conspicuous biota and can discriminate between some species or communities because of the differences in their reflective properties. Discrimination and detection is empirical in that it is not necessarily important what the theoretical reasons are for the differences in reflectivity, just as long as the differences are measurable and consistent.

Electromagnetic radiation has poor penetration through water and acoustic remote sensing is more appropriate for deeper and/or turbid water. Acoustic remote sensing can be thought of as an extension of this empirical approach: the reflectance of sound can depend upon the properties of the sea floor. However, the acoustic reflectance is more usually determined by physical properties of the sea floor than the associated biota, except where the biota itself forms the structure of the seafloor as biogenic reefs, mussel/oyster beds or maerl beds. The habitat is inferred from the relationship between the acoustic properties (intensity of backscatter/degree of absorption) and data for the habitat (samples and observations). An empirical approach may still be appropriate, but the link between reflectance and biota is less direct than for EMS devices. It could be said that the acoustic link with the physical habitat is a proxy for the full biological habitat.

This indirect empirical link may not be obvious to mappers. But incorporating depth data with acoustic reflectance effectively divides up similar acoustic sea floor types on the basis of biological depth zones – which is inferential modelling.

Habitats are defined on the basis of their biological and physical environmental characteristics. Habitat definitions include a description of the physical environment *suitable* for that habitat. Modelling can become more apparent when statistical, theoretical or expert judgement is used to divide up the physical environment into classes that may be correlated with these descriptions of a habitat's suitable environment. This is a more obvious form of habitat suitability modelling. Such models may become quite complex when the physical habitat factors needed to predict habitat suitability are themselves inferred from remotely-sensed data. This complex network of relationships is apparent in desk-top models using multiple data sources.



The relationship between biological habitat (community structure), physical habitat data and remotely-sensed data for three different habitat modelling scenarios

What data do you need for habitat mapping?

Empirical survey techniques and habitat suitability modelling can be contrasted. For empirical techniques, any data will do as long as it works. The best techniques have high resolution, precise measurements and good powers of discrimination.

As soon as some form of habitat suitability modelling is involved, then the more biologically relevant the better. But what is biologically relevant? Species are adapted to live under a particular set of conditions, requiring a substrate suitable to their body form and an environment suitable to their physiological needs and tolerances. The same holds true for communities and their characterising species (leaving aside doubts about the community concept). However, not all species respond to the same factors. Habitat criteria can be divided into firstly those that are universally important and secondly, those that are important for certain biological communities, but not others.

The two most universally relevant factors are:

- Depth below datum in the subtidal, or height above datum in the intertidal (measured directly by remote sensing)
- Substratum (determined from remotely-sensed data directly and inferred from point sample data)

A more comprehensive list might also include the following (many of which are not independent variables but interrelated):

- Rock type/features and bed-forms (may be derived from high resolution bathymetry)
- Selected sediment characteristics, e.g. median particle size, silt content (may be inferred or modelled from point samples and remotely-sensed data)
- Topography (may be derived from depth)
- Physiographic form (from depth, coastline and topography)
- Light (measured at points, detected by satellite imagery and correlated with depth)
- Salinity (point measurement and may be correlated with physiographic feature)
- Temperature (at a biogeographic scale) (measured and also detected by satellite sensors)
- Water energy (derived from measurements and hydrodynamic modelling)
- Wave action (coastal areas to 50-70m depth) (wave heights measured and wave base energy modelled)
- Fetch (from physiographic shape, wind characteristics)
- Currents and bed stress (measured at points and modelled using topography and bathymetry)

Some of these data sets are primary in the sense that they can be collected through commissioned survey. Others are modelled using a variety of measurements and data sources. These factors must be carefully assessed as to the availability of data and information at the appropriate scale and usefulness for the modelling of the full range of habitats or a selected list of habitats. The biological relevance of these factors are not universally applicable and depend upon the habitat types in question.

Rocky substrata

Rocky substrata are generally colonized by vegetation; as such the photic depth (depth of light penetration into the water column) has a more crucial importance. However, bare rocky seafloors are also found, probably where rock slabs alternate with coarse sand, whose abrasive effect could be determinant under high near-bed stress. As surveying photic vegetation usually is difficult (because of its inshore location), abiotic parameters are crucial in modelling its presence. In the case of subtidal kelp prediction for example, the turbidity regime is most important.

In the intertidal zone, seaweeds are known to be distributed according primarily to their height on the shore (in relation to tide flooding) and wave exposure and secondarily to the prevailing light, temperature and nutrients regime. Seaweeds differently suffer from stress when they are out of the water, so flooding frequency is a key parameter to account for their presence. Flooding frequency at a given elevation is driven by the tidal regime, so using a tide model, water levels can be translated into annual percentages of immersion. This requires that both reliable DEM's (Digital Elevation Models) and accurate tidal data are available.

While a certain amount of turbulence seems necessary for seaweeds to thrive, a high level of wave exposure tends to prevent the fixation of juveniles. While different species may accept the same time of emersion they may not stand the same level of exposure, as is the case for e.g. *Ascophyllum nodosum* and *Fucus vesiculosus*. There are several ways to estimate wave exposure in the intertidal zone, either from a proxy (fetch derived from wind data) or from wave data themselves where available. Wave data always come from offshore buoy measurements or models and they can be propagated to the inshore reaches only if a high quality bathymetric DEM is available.

Soft substrata

Identification of sediment type can be done from acoustic imagery with validation by samples. In case no surveys are available, historic hydrographic maps may show bottom types. Sediment is highly shaped by the near-bed stress, and often a good correlation exists between the grain size and the bed stress. This should be kept in mind when associating these variables statistically. On top of this, bed-forms (e.g. sand waves) resulting from the complex action of the near-bed stress (magnitude and direction), slope, aspect and grain size do locally influence the presence of biological communities. If bed-forms are not directly mapped by acoustic surveys, there is a way to predict their presence using these parameters at a suitable resolution with regard to their expected spatial size (there are considerable variations in bed-form heights and wavelengths). Near-bed stress in particular is derived from a combination of the maximum current velocity and the swell orbital velocity. Often, presence/absence data of bed-forms is sufficient for habitat mapping (an overview can be found in Seabed Sediment Classification)

In order to classify depth zones according to EUNIS, data on light attenuation and on the wave base are needed. The former results can be obtained from ocean colour satellite data and when combined with depth it yields the photic depth (the lower limit of the "infralittoral zone"). The latter is the depth to which waves can penetrate the sea and thus disturb the seabed, and can be used to predict the lower limit of the "circalittoral zone". It is obtained by combining wave statistics and the local depth.

Additionally, on sediment-dominated platforms such as along the Belgian part of the North Sea, the importance of detailed grain size classes should be stressed as they correlate highly with the presence of specific benthic communities (Van Hoey *et al.*, 2004).

Links to resources:

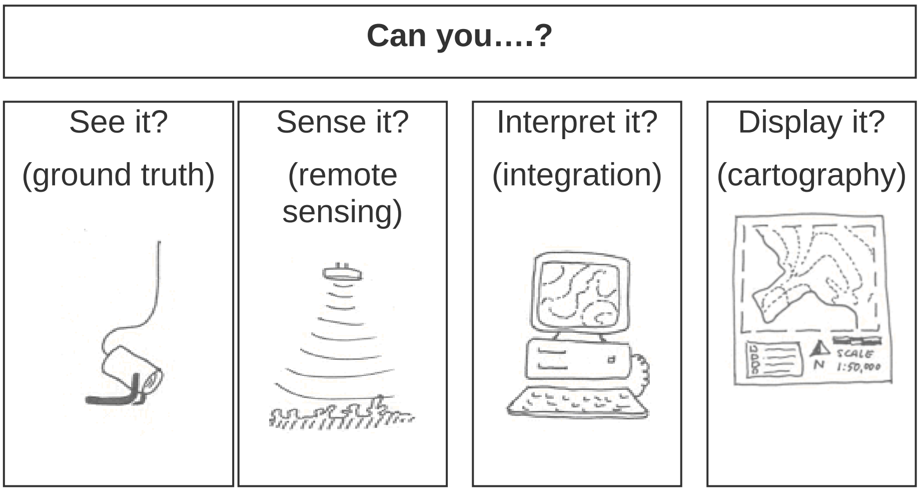
Worked example: Seabed Sediment Classification

Worked example: mncrform.pdf

Worked example: 04 05 introduction.pdf

What are the limitations of habitat mapping?

Habitat maps show the predicted distribution of habitat classes and other information collected by sampling and remote sensing or modelled using data from indirect sources. Habitat maps only show snapshot in time and their representation of the distribution of habitats at any subsequent time will depend on the degree of natural variability present in the area shown on the map. Other than potential temporal changes, there are other limitations to the nature of this habitat information imposed by the way data are collected, interpreted, displayed and stored. These limitations must be understood since they have profound implications on the design of a mapping programme and so that the end user's expectations of habitat mapping are realistic. The following figure shows the main limitations.



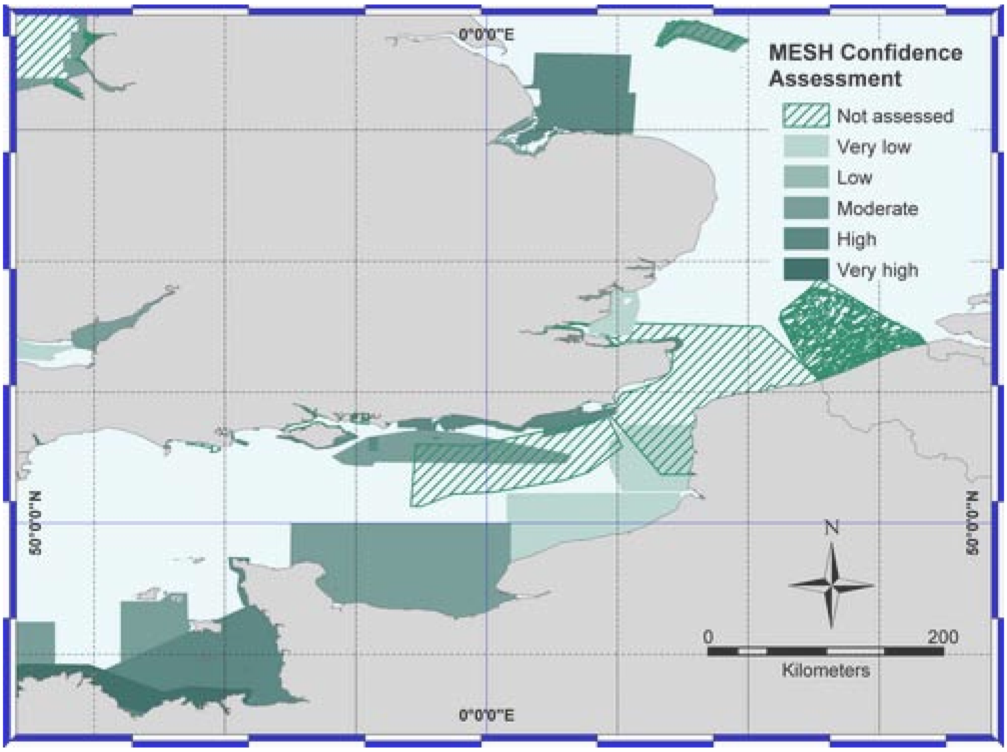
To show a habitat on a map, you must answer 'yes' to each of these four questions. For a variety of reasons:

- You may not be able to detect the habitat of interest either because the ground-truthing techniques are unable to 'see' it or because the remote-sensing and interpretation techniques cannot separate out the target habitat from other similar habitats.
- You might not be able to display the habitat on your map at the chosen scale because its dimensions are too small.

In reality, it is unlikely that you will be able to make such a categorical statement for each habitat likely to occur in the area of interest, the answer is more likely to be more equivocal along the lines of 'maybe', 'probably' or 'possibly'. The degree of certainty with which you can answer the questions will depend upon our knowledge of the habitat itself: some habitats, for instance mussel beds, have a long history of scientific investigation so their physical and biological structure and the physical factors important to their functioning are relatively well understood. In contrast, we know very little about many deep sea habitats and hence whether it is possible to detect and then map such habitats.

Earlier sections have described the potential problems associated with scale, interpreting images and cartography. The size of patches of different habitats on the seabed varies enormously depending on prevailing environmental conditions and the underlying geology of the seabed. It may be possible to map such heterogeneity where the habitat patches are large compared to the resolution of the sensor and the required map scale. Unfortunately, there are many areas where such heterogeneity occurs over very small areas either beyond the detection limits of sensors or if detectable, at such a scale that the patches cannot be drawn on a map.

All these limitations will affect the quality of the final habitat map. Quality is directly linked to how well a map fits its intended use, and how much confidence it offers to the end user. Quality is often measured in terms of the accuracy and precision of a product. Assessing the quality of a map is a complex process but is clearly important to the end user, particularly when they have to make important decisions based on that map. The section *How good is my map?* of the MESH Guide describes the process for evaluating the quality of the map. The MESH Project developed a scheme supported by a web-based tool to assess the confidence of a habitat map (confidenceAssessment.html) so that it could be displayed on the MESH webGIS (www.searchMESH.net/webGIS): the first time such a scheme has been developed.



A map of habitat mapping studies showing their confidence assessed using the MESH Confidence Tool

Habitat mapping studies collect a huge quantity of data that is eventually compressed into a habitat map. Some of these data are intermediate products on the journey towards the map. However, some information that has been recorded cannot be shown as habitat polygons on the final map: for example, the names of all the individual animal and plant species recorded from samples or observations of the seabed do not form part of the habitat description. Nevertheless such information is not 'lost' and important aspects (presence of a rare species) can still be plotted on a map in some other way if needed. It is vital that all information recorded at each stage in the habitat mapping process should be stored in database so that it is never lost and is available for further analysis and display, particularly at some future date. To maximise the value of data, it should be carefully described in a standard manner and properly archived so it always remains available for future work. Data management is covered in the following section and in more detail in *How do I collect my data?* and *What can I do with my map?*.

Links to other section sections

How do I collect my data?

How good is my map?

What can I do with my map?

Links to resources

Confidence Assessment. html

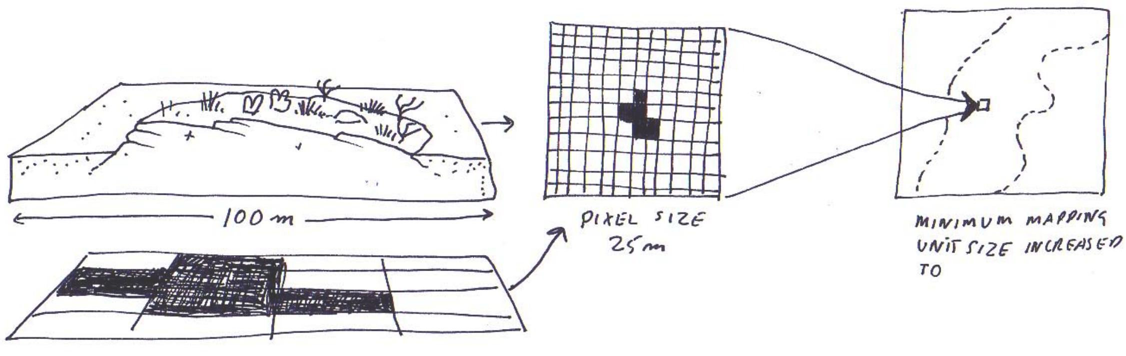
Links to websites

http://www.searchMESH.net/webGIS

Heterogeneity and aggregating data

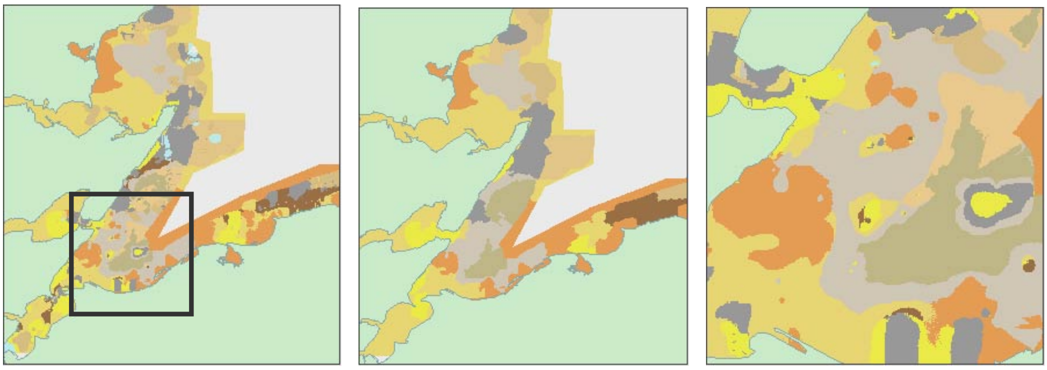
Heterogeneity of the seabed presents mapping with particular problems and necessitates some difficult decisions when planning the data collection and the format of the final map. Heterogeneity is relative to mapping scale, but involves some form of generalisation to smooth out variability to create an overview. What features will be used to create the overview? What will be shown and what detail will be 'lost'? How will fine-scale variability be smoothed out and how will the variability be summarised?

In the figure below, if a pixel of 100m were to be the minimum size that could be mapped, would the pixel be labelled as 'sand' (the majority of the 25m pixels are sand), or 'reef present' (if the map was primarily to show reef distribution) or 'mixed reef and sand' (to preserve some information by creating a mixed class)? It is inevitable that if a patchy and rare habitat is encountered, taking the majority habitat will always result in the under representation of the potentially important habitat with serious implications for management.



A small rocky reef with some rare and important soft corals occur in a sediment plane. This can be mapped as a small cluster of pixels each representing 25m on a map at a scale of 1:10,000 (for example). However, if the habitat map is of a moderately large area and the map is reproduced at a scale of 1:50,000, then this group of pixels will be vanishingly small. Is the reef important or not? If the occurrence of the reef is considered important, then it must be represented as a point occurrence overlying the more general, lower resolution habitat map.

Heterogeneity is commonplace in mapping. Most maps smooth out variability to a greater (heterogeneous ground) or lesser (homogeneous ground) extent. If maps are showing some generalisation of habitat distribution and hiding variability, the implication is that other habitats might be found other than the one shown on a map. If this is the case, in what way can maps be used to predict habitat distribution (e.g. for monitoring favourable status)? Clearly, this issue becomes more prominent as maps become broader scale.



Zooming out of a fine-scale map (left) will result in many map objects becoming too small to represent satisfactorily (middle) and a process of generalisation may be required to eliminate the smallest polygons (right).

The first map (left) is at a scale of approximately 1:25,000 and the fine-scale habitat detail is readable. When the map is expanded to a scale of approximately 1:100,000 (middle) the detail is too fine to read and some form of generalisation (right) reduces the detail but makes the map more readable. The generalisation process raises a number of questions: Does the generalised map meet the management needs for information at this scale? If it does, then the fine detail may be a distraction. What form should the generalisation take? Filtering out small polygons in favour of the modal class in the neighbourhood? Amalgamating similar habitat classes? Using a higher EUNIS class?

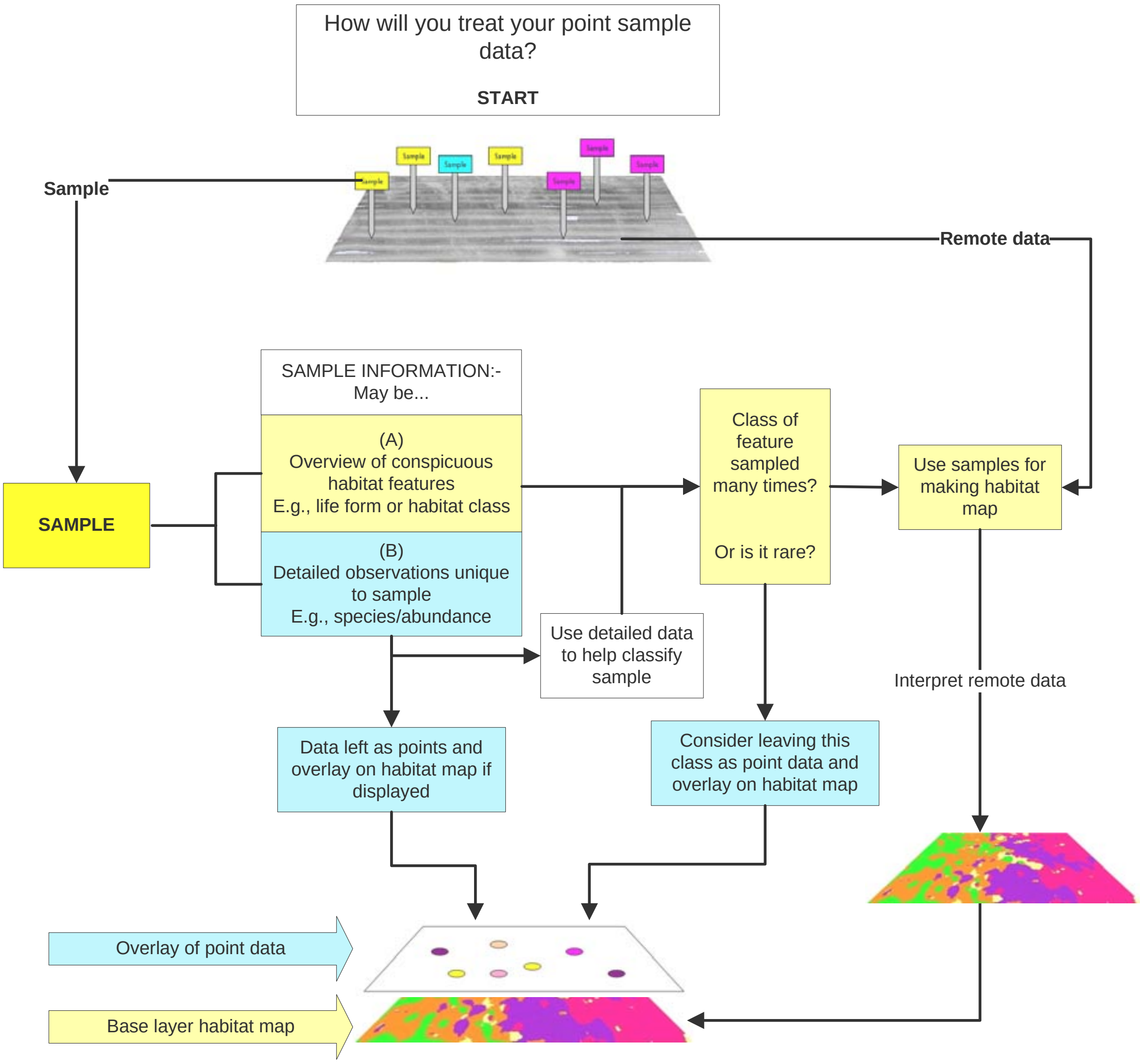
Whatever form of generalisation is used, information is lost to the map. The ‘hidden’ information can still be used to describe the variability of the new reduced classes and, of course, the finer scale can always be shown as a series of maps at a large scale.

Using data collect but not mapped

Habitat maps show the habitat classes as defined by their common characteristics. However, it is likely that your point sample data will contain much more information than can be used to create a habitat map, such as details of substratum cover and species abundances.

Information is not lost just because it cannot be displayed as part of the base layer habitat map. There are many ways of using and displaying information. The strength of the habitat map is that it gives spatial context for all the other information.

The flow diagram below summarises the process of utilising and displaying sample information with regards to habitat mapping based on remotely-sensed data. The sample points will need to be tagged with habitat class information and each class being sampled a few times before the samples can be used to interpret the remote data in terms of habitat classes. Other sample information can be displayed as an overlay of point data.



Scheme of how to utilise and display sample information with regards to habitat mapping based on remotely-sensed data

Lastly, the detailed information can be used to draw up a detailed description of a habitat class, giving information on likely diversity, species composition and variability that might be encountered. However, this information is not part of the map as such but should be made available to the end user to help their understanding of the habitat classes present on the map. Such information is often presented in structured format supported by photographs or video clips of the seabed (see following figure for an example)

Habitat type	Characterising species or sediment	Biotope code and description	
Mixed sediment	Ophiothrix fragilis beds on mixed sediments	SS.SMX.CMx.OphMx: Ophiothrix fragilis and/or Ophiocomina nigra brittlestar beds on sublittoral mixed sediment	
			

Ophiothrix fragilis (and lesser numbers of *Ophiocomina nigra*) were found forming very dense beds on mixed sediment and more rocky substrata.

Species	Density	Species	Density
Ophiothrix fragilis	80	Pomatoceros lamarcki	10
Lumbrineris gracilis	30	Pisidia longicornis	10
Melinna elisabethae	20	Nephtys kersivalensis	10
Terebellides stroemi	10	Glycera alba	10
Prionospio fallax	10	Galathea nexa	10

An example of a habitat description to support the habitat classes shown on a map.

How much confidence can we place in habitat maps?

It is easy to assume that habitat maps accurately show which habitats are found on the seabed. But there are many ways in which errors and inaccuracies can occur in a map or why the map may not truly represent the reality of the area mapped. The sources of error and variability include the technological and analytical limitations, lack of sufficient samples for interpretation and the limitations of cartography.

Anyone using a map should be concerned about its accuracy. Can maps indicate precision and accuracy? More importantly, how much confidence can a user place in a map? How reliable is it? These are very difficult questions to answer. We must be aware of all these issues and the limitations of habitat maps so that users have a realistic expectation of the maps without undermining confidence in the valuable contribution habitat maps undoubtedly make to marine planning and management.

Confidence is an assessment of how reliable the map is given its purpose (how well a map meets the objectives set).

Accuracy is a mathematical measure of how successful the map is in predicting habitat occurrence. Sample records (ground validation data) are superimposed on a map and the correct and incorrect predictions counted.

Precision is a measure of the positional accuracy of a habitat boundary.

Confidence is perhaps a more useful concept in mapping although confidence could be supported by accuracy measures. Confidence is a complex issue because it is multifaceted: Scale, resolution and information content of habitat maps are all issues that are interconnected with confidence; information content can be traded off against accuracy (accuracy of a map can be increased by sacrificing information content through combining habitat classes). Users need to be aware that accuracy, precision and confidence have different meanings and are gauged in different ways.

Temporal change and mapping as a long-term process

Because habitat mapping involves an element of inference between the ground-truthing data and the remote-sensed data, all maps are the best approximations to reality that can be achieved with the data available. Over time, and with improvements in survey techniques, it is likely that the data quality and intensity of ground-truthing will increase, enabling improvements in the quality of the habitat map. Thus, over time, the maps should increase in accuracy. The speed of improvement is likely to be linked to demand for improved quality, such as led by end-user needs for more detailed maps of higher resolution.

Habitat mapping is thus an ongoing process of developing our knowledge of the marine environment. In a sense, there is no specific end point to the habitat mapping process since the maps are predictive and needs to be tested and further improved through usage. A habitat map is a statement of our best estimate of habitat distribution at a point in time, making best use of the available knowledge.

In addition to the limitations placed on maps by the quality of the data used to produce them, it should be born in mind that the marine environment is often very dynamic and that change in habitats will occur naturally over time. Thus even if the mapping data were highly accurate at the time of survey, leading to a very high quality map, if the area mapped is highly dynamic then at the time the map is used (perhaps some considerable time after the original survey) it may not fully represent the current situation.

The degree of change in habitats varies considerably, from hours to decades and centuries; whether the change matters depends on the scale of the mapping and the end users needs of the map. These issues are discussed further in *How good is my map?*

Links to other sections

How good is my map?

Data management

Habitat mapping studies generate considerable volumes of data; it is most important that sound data management practices are put in place to describe how the data were collected and processed and to describe how the resultant maps were developed. Metadata is the term used for the information that describes data. Poor data management can result in valuable data being lost (because it is not properly archived) or the data being passed to others without sufficient documentation to know the quality and possible limitations of the data.

Each study typically includes data of many different types (remote sensing and ground truthing), some of which can be very large in volume (e.g. multibeam sonar data). Sound data management practices are therefore extremely important to track the data from the time they are collected, through the processing stages, and ultimately to when they are archived. The MESH Project developed a data management model supported by a database that will capture all the relevant metadata; a blank version of the database is available for download (see MetadataDataModel_v5.xls). This database complies with international metadata standards and offers the user reports to export their data in a suitable format to send to data archiving centres and/or contribute metadata to international metadata catalogues. The MESH Project also offers data exchange formats (see *What can I do with my map?* to enable users to store their data in a simple format that can be readily assimilated into other data collation activities.

Data management must be one of the elements considered during the planning stage of a habitat mapping project. The following section sets out the main considerations for planning such mapping studies.

Link to other sections

What can I do with my map?

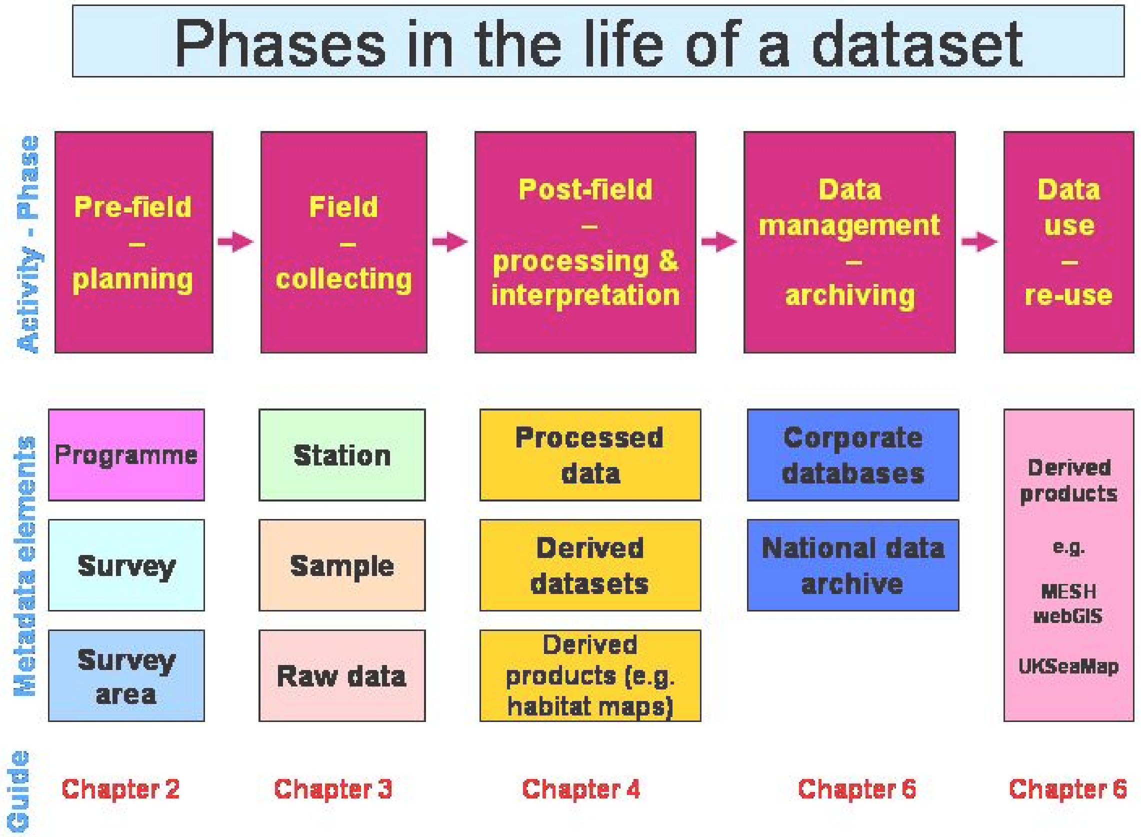
Links to resources

MetadataDataModel_v5.xls

Recording metadata– a journey from inception to maps and beyond

Each habitat mapping study has a number of phases from the initial planning phase through to the survey itself, data processing and interpretation and on to the final map production. For the data in this process, metadata should be added at each stage to document the data as it passes through each stage. Often, however, the datasets from a single survey will have a life beyond the map production stage and end up in different places (organisations, databases, web portals) and be used for other studies. It is important that all the (relevant) metadata accompanies the dataset as it moves along this journey and from place to place.

The figure below (Phases in life of data) provides an overview of the different phases in the life of a dataset; the first two (pre-field and field) have been linked to the levels in the Survey organisation model (see *How do I collect my data?*), with all phases linked to the relevant section in the MESH Guide. A more detailed portrayal of the relationship between the phases, the survey model, subsequent data processing, archiving and re-use is explained in How do I collect my data (see also MetadataDataModel_v5.xls). In the spreadsheet (MetadataDataModel_v5.xls), individual samples taken during a survey (e.g. a video tow) are linked both with other data at the same station and survey and with similar types of sample as they get processed following the survey, subsequently archived, contributed to national datasets and then used in other studies.



Phases in the life of a dataset, showing relationship to elements of the Survey structure and to sections in the MESH Guide

The spreadsheet also shows the relationship of this process to other databases developed in MESH:

- Metadata catalogue – a catalogue of habitat maps and related datasets (see www.searchMESH.net/metadata). The catalogue includes entries for datasets and products (maps) emanating from single surveys, together with records of corporate and national databases, and products derived from these larger data sources.
- Survey database – a database used for planning surveys, which provides information relating to the Survey and Area parts of the metadata model.

Links to other sections

How do I collect my data?

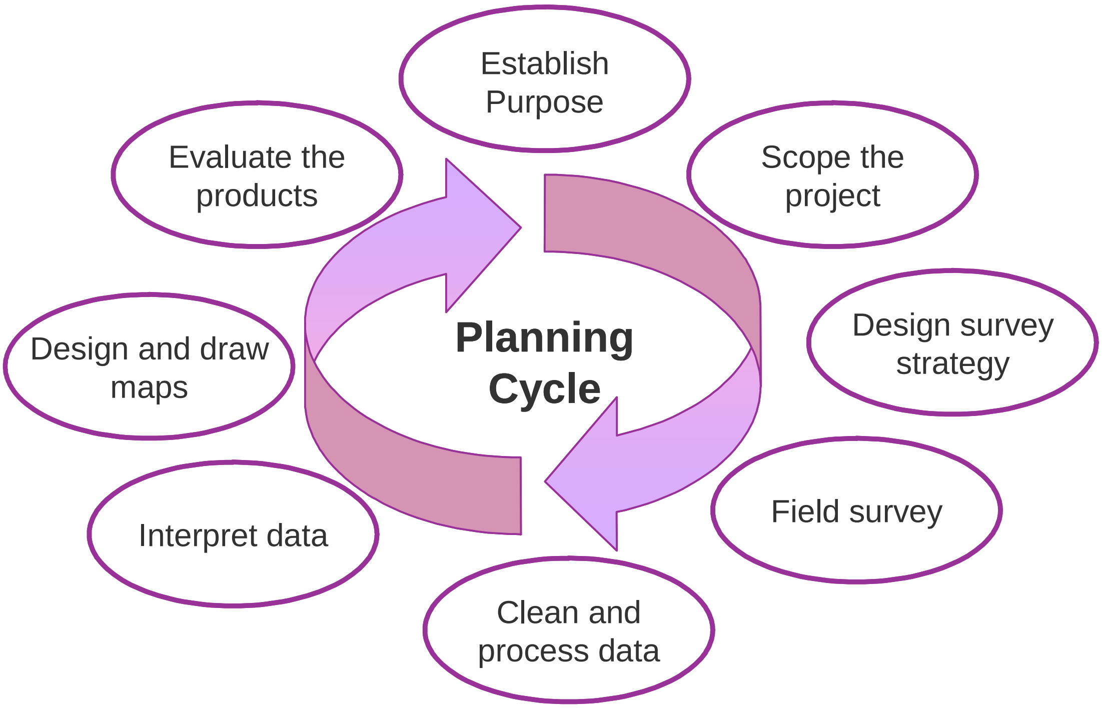
Links to resources

MetadataDataModel_v5.xls

How do you plan for habitat mapping?

Maps must be fit for purpose and planners should have a clear idea of the scale, resolution and level of habitat detail required in the final map(s), together with the knowledge of how the maps will be evaluated against the original aims and objectives to ensure the meet the necessary quality assurance standards. Planning a habitat mapping study involves a consideration of each of the stages of the habitat mapping process to ensure all necessary information is collected for the evaluation of the final map.

Once the need for a habitat map is clearly identified, planning the mapping process starts with setting realistic aims and objectives to deliver a map that is fit for purpose. An evaluation of the available information (possibly requiring a short desktop study) is required at the outset to clearly establish the how to acquire the necessary data. Where the planning cycle identifies suitable data are available, it may suggest a desk-top mapping project to derive the required habitat maps from the interpretation and synthesis of existing data. However, if critical habitat data are lacking at the required scale and level of confidence, new surveys will need to be commissioned. A survey strategy will need to be planned, choosing techniques and strategies for deployment to collect appropriate data for the resulting maps to meet their stated purpose. The next stage in the planning should focus on the data analysis, interpretation and cartography. Ideally, the plan would include a flow chart through these stages showing the type of data required at each stage of the process. Finally, planners must consider the type of evaluation required at the end of the mapping process to ensure that appropriate data are available; for instance, if a statistical assessment of accuracy is required the survey strategy will have to collect an independent set of ground samples for validation. The planning cycle is summarised in the following figure.



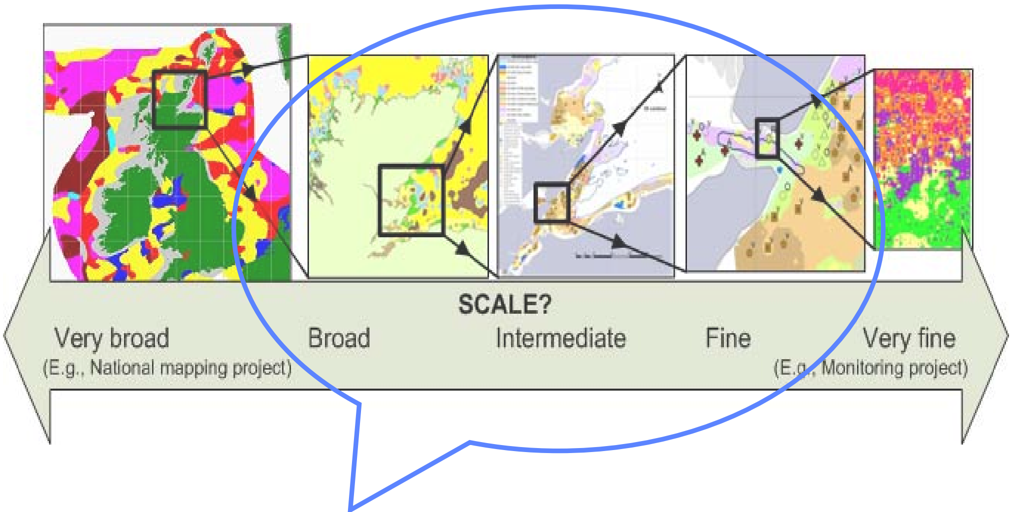
The planning cycle for habitat mapping projects

It is important that there is a good overview of the whole mapping project at the planning stage to ensure that all the necessary data and information are collected. It is likely that planning will involve visiting each of the major mapping stages in an iterative manner until the final plan becomes clear and fixed and can proceed to either the field survey phase (*What do I want to map?* and How do I collect the data?) or the map production phase (*How do I make a map?*) if sufficient existing data are available.

What are the stages in habitat mapping?

Habitat mapping is best considered as a process, to be tackled in a series of stages that will ultimately result in your required map or maps. This MESH Guide is set out in a series of sections to follow the main stages in this process. The section Data management outlines the flow of data during this process and introduces the need to record information (metadata) at each stage so that the data and resulting maps are adequately described for future use.

STEP 1: PURPOSE OF THE MAPPING PROJECT: What is the purpose of the habitat mapping project and what scale are you interested in?



Most habitat surveys lie between the broad and fine-scales: Very broad scales are likely to be national mapping projects and very fine-scale surveys will probably be special surveys targeting particular biota or habitat parameters.

You may have chosen more than one scale? If so, you will need to scope each scale separately and consider how the different scale outputs will be related to each other.

STEP 2: SCOPING THE PROJECT: What is the scope of the survey? This will involve matching the purpose to the extent and resolution of the survey. What are the key environmental parameters that will impact on survey effort?

- DESKTOP STUDY (DETERMINING INFORMATION GAPS): What information is available; what new information is required? An evaluation of the available information will be made against the information requirements. This will help refine the scope of the work to be done.
- SPECIFICATION OF WORK PROGRAMME: At this stage, it should be possible to draw up a detailed report on the specification of the information requirements of the mapping programme. This should included making the best use of existing information, planning

STEP 3: DESIGN OF THE SURVEY: STRATEGY & SELECTION OF TECHNIQUES: What options are there for designing your survey strategy? Is there an optimal strategy? What are suitable techniques and what are the implications for costs and effort? It is important to build in some flexibility to accommodate environmental and weather conditions and knowledge gained as the

STEP 4: UNDERTAKE ANY SURVEY WORK REQUIRED: Ensure that the data collected gives value by following Recommended Operating Guidelines (ROGs).

STEP 5: DATA PROCESSING: Ensure that data quality is maintained through the data editing and processing stage.

STEP 6: ANALYSIS, DATA INTEGRATION, MODELLING AND INTERPRETATION: A plan for analysis and interpretation should be part of STEP 2 although this may need revision after data exploration. Can you assess map accuracy and confidence?

STEP 7: CARTOGRAPHY AND THE GIS PROJECT: The primary output will be a habitat map. This should show the appropriate amount of information and detail for the map scale(s). The habitat map should be fit for its intended purpose. The supporting data will be contained in thematic layers that can also be displayed as maps or as separate attributes of the habitat types (e.g. in GIS attribute

STEP 8: EVALUATION: This is somewhat different from assessing map accuracy and confidence as part of the data analysis and interpretation. The final evaluation should assess how useful the map is and, particularly, if it makes predictions about habitat distributions that are reliable. A good habitat map should prove itself through usage (with the understanding that the application is appropriate given the limitations of the map). The map should also stimulate further investigation

Links to other sections

Data management

Summary

Habitat mapping is a process that ultimately generates a habitat map to meet a specific and clearly defined need.

A habitat map:

- Supplies information to meet a purpose;
- Predicts the distribution of habitats;
- Applies a habitat classification scheme to observed data; and,
- Requires thorough planning and scoping to ensure it meets its stated purpose.

A habitat map is not:

- Definitive
- Simple or simplistic

The subsequent sections of the MESH Guide describe each of the stages in the habitat mapping process, with the final section providing examples of how habitat maps were used to solve real problems.